DOCUMENT RESUME

ED 339 360 IR 015 311

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TITLE The Effects of Expert Systems Training versus Content-Based Training on the Troubleshooting Achievement of Onan Corporation Service Personnel. Training and Development Research Center, Project Number Forty-Eight.
INSTITUTION Minnesota Univ., St. Paul. Dept. of Vocational and Technical Education.
PUB DATE Apr 91
NOTE 172p.
PUB TYPE Reports - Research/Technical (143) -- Tests/Evaluation Instruments (160)

EDRS PRICE MF01/PC07 Plus Postage.
DESCRIPTORS Analysis of Variance; Electronic Equipment; *Electronic Technicians; Hypothesis Testing; *Industrial Training; Instructional Design; *Intermode Differences; Postsecondary Education; Pretests Posttests; *Problem Solving; Technical Education; Training Methods; *Troubleshooting

ABSTRACT

This study compared the effectiveness and efficiency of trainees in the Onan small products gasoline course under two training curricula: (1) the control group curriculum was the in-place course on the Emerald generator set; and (2) the experimental group curriculum was essentially the same with the addition of one lesson based on methods used by experts in solving complex troubleshooting problems and some of the procedures that the experts had developed for themselves, and the substitution of a second lesson which added the use of a problem space map. The study focused on ways of presenting material in a cohesive program that would help students understand and troubleshoot electrical/electronic circuits. Both groups received a pretest on the course material and were tested again after the instruction was completed. Results indicated that if novices are given information on troubleshooting methods and how to use them, they will be able to solve a given problem faster than other novices not given this information. It is concluded that further research is necessary to determine whether the troubleshooting knowledge or troubleshooting procedures had more influence on the ability of the experimental group to perform a troubleshooting task. Appendices contain questionnaires, consent forms, achievement tests, treatment outlines, and troubleshooting protocols. (42 references) (DB)

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TRAINING AND DEVELOPMENT RESEARCH CENTER

Project Number Forty-Eight

THE EFFECTS OF EXPERT SYSTEMS TRAINING VERSUS CONTENT-BASED TRAINING ON THE TROUBLESHOOTING ACHIEVEMENT OF ONAN CORPORATION SERVICE PERSONNEL

Edward John Westerdahl

April 1991

university of minnesota
DEPARTMENT OF VOCATIONAL AND TECHNICAL EDUCATION • ST. PAUL, MINNESOTA

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Contents

The problem		1
Review of the literature		20
Experimental design		33
Presentation, analysis and interpretation of the data		49
Summary, conclusions, recommendations		59
References		65
Appendices:		
A	Registration confirmation worksheet	68
B	Research consent form	72
C	Control and experimental group registration and examination scores data	74
D	Declarative knowledge pre-test and answer sheet	79
E	Declarative knowledge post-test and answer sheet	94
F	Control group treatment outline	109
G	Experimental group treatment outline and troubleshooting method information sheets	111
H	Procedural performance test instructions	119
I	Control group troubleshooting protocols	121
J	Control group problem behavior maps	129
K	Experimental group troubleshooting protocols	142
L	Experimental group problem behavior maps	150

List of Tables

1	Troubleshooting -vs- training ability of the trainer as it relates to the type and number of troubleshooting methods learned by the trainee.	3
2	Characteristics of well- and ill-structured problems.	23
3	Bloom's cognitive taxonomy.	28
4	Treatments and evaluation methods used in this study.	33
5	Troubleshooting methods used by expert troubleshooters in Onan schools, and taught in the experimental course curriculum.	35
6	Subject matter expert responses used to develop Emerald I generator set "quick checks" troubleshooting method.	36
7	Subject's mean experience levels, by group, from this study and Johnson's (1987) study (figures in months).	38
8	Comparison of mean differences and t ratios of pre-test scores of control and experimental groups from the pre/post knowledge examination.	50
9	Comparison of mean differences and t ratios of post-test scores of control and experimental groups from the pre/post knowledge examination.	52
10	N, mean, standard deviation, error, and confidence intervals for control and experimental group pre-test and post-test scores.	53
11	Two-way ANOVA of control and experimental group pre-test and post-test scores.	54
12	Scheffe′ procedure for ANOVA on pre/post-test data for control and experimental groups.	54
13	Comparison of mean differences and t ratios of pass/fail troubleshooting scores from the procedural performance examination.	55
14	Rank order of troubleshooting times for the procedural performance examination by group, showing the number of subjects with each troubleshooting time score.	56
15	Control class registration data (listed in months)	75
16	Control class examination scores	75
17	Experimental class registration data (listed in months)	76
18	Experimental class examination scores	77

19	Pass/fail scores for the procedural performance examination by group, showing the number of subjects in each group passing and failing the procedural performance examination.	78
20	Rank order of troubleshooting times for the procedural performance examination by group, showing the number of subjects with each troubleshooting time score.	78
21	Control group treatment curriculum outline.	110
22	Experimental group treatment curriculum outline.	112
23	Troubleshooting methods discussed in the troubleshooting methods lesson of the experimental treatment.	113

List of Figures

1	Model of the experimental design	8
2	Emerald I generator set control problem space	10
3	Onan Emerald I generator set	39
4	Control group treatment curriculum outline	40
5	Experimental group treatment curriculum outline, with added lessons in boldface.	41
6	Emerald start and run circuit diagram used in this study, adapted from Johnson's study (1987), used by permission.	43
7	Easy-likely troubleshooting method grid format	114
8	Big-3 troubleshooting method, level 1	115
9	Engine, generator, and control level 2 subdivisions of the big-3 troubleshooting method.	115
10	Half-half troubleshooting method diagram	117
11	Systematic troubleshooting method flow chart.	118
12	Control ss# 1 problem behavior map.	130
13	Control ss# 2 problem behavior map.	131
14	Control ss# 3 problem behavior map.	132
15	Control ss# 4 problem behavior map.	133

16	Control ss# 5 problem behavior map.	134
17	Control ss# 6 problem behavior map.	135
18	Control ss# 7 problem behavior map.	136
19	Control ss# 8 problem behavior map.	137
20	Control ss# 9 problem behavior map.	138
21	Control ss# 10 problem behavior map.	139
22	Control ss# 11 problem behavior map.	140
23	Control ss# 12 problem behavior map.	141
24	Experimental ss# 1 problem behavior map.	151
25	Experimental ss# 2 problem behavior map.	152
26	Experimental ss# 3 problem behavior map.	153
27	Experimental ss# 4 problem behavior map.	154
28	Experimental ss# 5 problem behavior map.	155
29	Experimental ss# 6 problem behavior map.	156
30	Experimental ss# 7 problem behavior map.	157
31	Experimental ss# 8 problem behavior map.	158
32	Experimental ss# 9 problem behavior map.	159
33	Experimental ss# 10 problem behavior map.	160
34	Experimental ss# 11 problem behavior map.	161
35	Experimental ss# 12 problem behavior map.	162
36	Experimental ss# 13 problem behavior map.	163
37	Experimental ss# 14 problem behavior map.	164
38	Experimental ss# 15 problem behavior map.	165
39	Experimental ss# 16 problem behavior map.	166

Chapter 1

The Problem

Many of today's service technicians waste vast amounts of time and money as a result of poor troubleshooting skills. It appears that technicians who have learned good troubleshooting methods from a good teacher are more efficient and effective troubleshooters. Expert troubleshooters have a different outlook on problem solving than novices; this was the conclusion of Johnson's (1987) study in association with the Onan Corporation. This follow-up of Johnson's study will attempt to determine if his recommendations and suggested training practices will make a significant difference in learning outcomes. The greatest concern and point of frustration expressed by trainees at the Onan factory schools is their inability to deal with electrical problems, solutions, and troubleshooting of control circuits. The students can give definitions for terms; and decipher the cryptic markings on a schematic diagram, but they cannot use the schematic diagram to tell what part of the circuit is involved during any given sequence of equipment operation.

Traditionally, technicians have gained troubleshooting expertise in two ways: on-the-job training or in civilian and military vocational-technical schools. In a vocational-technical course, technicians are taught the troubleshooting method(s) applicable to the equipment they are studying. For instance, in a course dealing with a superhetrodyne radio, technicians will be taught to divide the possible faulty circuitry into two parts and check for proper signals at an arbitrary test point. The technician will continue to use this "divide by two" method until the faulty circuit is determined. After the faulty circuit is found, the technician will use a more linear method of troubleshooting to pinpoint faulty component(s). When a technician learns these troubleshooting methods and practices them, they will be proven through empirical investigation and be used more often with increased speed and accuracy. Eventually, the troubleshooter will recognize "quick checks"— a mental list of circuits and circuit components to check first, for they fail most often.

On-the-job training also offers a multitude of troubleshooting experiences through which to learn troubleshooting methods, but the results may be less desirable. If the teacher is a good troubleshooter and a good trainer, the technician will learn many troubleshooting methods and ways in which to use them. If the teacher is a poor troubleshooter and a good trainer, the technician will learn poor troubleshooting techniques and will perpetuate the myth that the "shade-tree" mechanic can effectively troubleshoot and repair complex equipment. This type of trainer often uses a "grocery list" or "shotgun" troubleshooting technique. This technique focuses on parts replacement and not on problem diagnosis--all parts that have been replaced in the past when this problem has developed are changed with little concern that they may have no bearing on the problem at hand. If the teacher is a good troubleshooter but a poor trainer, the technician may develop "superstitious knowledge" whereby all problems are approached with only one method of troubleshooting. ("If all you have is a hammer, all problems look like nails.") All problems are treated with the same cure, whether that cure is applicable or not. If the teacher is a poor troubleshooter and a poor trainer, the technician will most likely learn no effective method of troubleshooting, and change whatever part "seemed to be causing the problem the last time this happened." Sometimes the failure of a single component causes the failure of many other components. In these cases, if the components are replaced piecemeal, the real problem will cause the replacement parts to fail also. Sometimes, the problem cannot be fixed until all of the failed parts are changed at the same time. Table 1 shows the relationship of the trainer's troubleshooting and training skills to the variety and quality of troubleshooting methods learned by the trainee.

Changing the ingrained habits of service technicians requires retraining and the emulation of different role models. Recognition of this need to change ingrained habits of service technicians is apparent in the Technical Training Department of Onan Corporation. The Onan factory school has, in the past few years, started to teach troubleshooting along

with service topics. By teaching specific troubleshooting methods, along with a different model of the control circuits of the generator set some technicians, already near the edge of understanding, may better understand the material and be able to repair the customer's equipment faster and more accurately. In the end both the customer and the shop win. The customer wins because the labor and parts charges are lower; the shop wins because more customers may be serviced in the same period of time.

Table 1

Troubleshooting -vs- training ability as it relates to the type and number of trouble-shooting methods learned by the trainee.

	Good Troubleshooter	Poor Troubleshooter
Good Trainer	Many methods	Grocery list
Poor Trainer	Superstitious Knowledge	Shotgun Approach

The Onan Technical Training Department provides training on electrical power generation and control equipment to Onan Distributor and Dealer service technicians, and to end users. The goal in the training department is to elevate the technical competency of the trainees attending the factory training courses to the level of effective troubleshooter. If this goal is accomplished, the trainees will be more able to service Onan products and to satisfy the customer with accurate, cost effective, and timely service. To achieve this goal, the Onan Factory Schools provide trainees with the information needed to service, repair and troubleshoot Onan equipment. The information provided to the trainees is product specific. Generalized information (*i.e.*, basic electrical theory) is not normally provided unless it is germane to the trainees' understanding of the product specific training. This is consistent with the view of factory training courses in industry (A.C. Jacobson, personal communication, December, 1987). Corporations do not have the time to teach trainees about basic

electricity or engine mechanics. Those principles applicable to the course being taught are given to the students in an abbreviated theory class which allows the trainees to "speak the language" well enough to understand the training course materials. This theory class is often simply a review of an electrical entrance test to help trainers understand the knowledge level of the group as well as individual trainees. It appears that most of the trainees in Onan factory schools have a basic understanding of how the engine and other mechanical components operate. A major problem lies in the fact that all of the products built by Onan have either DC or AC control and/or generation circuits. Most of the trainees are unsure of how these circuits operate, and how to go about troubleshooting them. The trainees have been taught how the sections (functional blocks) of the equipment operate, but are not specifically taught how to troubleshoot the equipment. Historically, an erroneous assumption was often made by the training staff, "If the trainees understand how the equipment operates, they also know how to troubleshoot the equipment." Research conducted by Johnson (1987) in the Onan Technical Training Department indicates this is not always the case. Often trainees can define terminology and follow lines on the diagrams, but they cannot put these two parts of the puzzle together in the workshop. Thomas and Litowitz (1986) called this "inert knowledge," when they stated, "It might be said that the student 'knows,' but that what they know is 'inert' or has no power of action" (p. 11). Trainees are able to relate facts and data at the knowledge level, but integrating these separate facts into a plan of action at the comprehension and application levels is a formidable obstacle for them.

Newell and Simon (1972) stated that learners will encounter two types of problems: well-structured, and ill-structured. Most of the technical problems encountered by Onan service technicians are of the ill-structured type. For example, the customer simply tells the Service Manager, "My Onan doesn't work." The service technician then not only has to determine what type of generator set the customer has but, in fact, whether or not it is really an Onan! The technician then tests the equipment to determine if it will crank, start, run,

produce electricity of the proper voltage and frequency, and stop on command. If the generator set passes all of these tests, the technician then interviews the customer for clues to the real problem, instead of asking questions of the customer first and acting on the responses to those questions. If the technicians check the whole generator set while looking for a problem instead of just the area or section where the problem exists, they are inflating the problem space to cover the complete generator set. Instead of enlarging the problem space, the technicians should be trying to shrink it to its smallest possible size by using good troubleshooting skills and troubleshooting methods which point to the real problem. The way that the technicians will make money for their employers is by reducing their search time for the problem and completing the problem repair within the time limits set forth in the Onan flat rate manual.

Problem space is used as a term to designate the area of search by the student in the total range of the equipment. If the student is searching for the solution to a problem in the cranking circuit of the control section of the generator set, but is searching in the schematic diagram for the generator, the student's problem space is involving much more than is required. The end result of technical training is that the student will be able to efficiently and effectively determine the proper problem space, and complete the repair in a minimum of time. The problem for this study, then, is to test a means of presenting material in a cohesive program to help students understand and troubleshoot electrical/electronic circuits. This problem raises several sub-questions:

1. Is there a difference between classes of trainees when they come in to the consumer products (recreational vehicle generator set, and portable generator set) classes, and should this difference be accounted for in planning the level of material for the classes?

2. Will there be a difference between the classes when they complete the small products training classes? Should some classes as a whole be given a specific level of certificate (attendance, completion, accomplishment, or outstanding accomplishment)?

3. Is there a difference between the ability of the classes to perform practical troubleshooting exercises on the present recreational vehicle (RV) generator set (the Emerald generator set)?

4. Can the trainees meet established repair times (from the Onan flat-rate manual) for the troubleshooting and repair of Emerald generator sets in the field? Does there need to be more emphasis on troubleshooting methods in the classes, or will the troubleshooting job aids in the service manuals perform adequately?

Objectives of the Study

1. To determine if there is a difference between the control and experimental group when they enter the Consumer products gasoline-powered generator set course; which specializes in the Emerald generator set; and when they leave this course.

2. To determine if there is a difference in the amount of increase in knowledge (gain scores) of the two groups, and if the difference in the training curriculum may have had anything to do with this difference in the outcome.

3. To determine if the teaching of troubleshooting methods will make a difference in the procedural effectiveness (ability to select the proper failed part) in troubleshooting a failed Emerald generator set.

4. To determine if the teaching of troubleshooting methods will make a difference in the efficiency (time required to troubleshoot a failed generator set.)

Hypotheses to be tested

1. There is no significant statistical difference between the declarative knowledge pre-test scores of the control and experimental groups as determined by a pre-test declarative knowledge cognitive instrument.

2. There is no significant statistical difference between the declarative knowledge post-test scores of the control and experimental groups; irrespective of the instructional methodology, as determined by a post-test declarative knowledge cognitive instrument.

3. There is no significant statistical difference between the mean cognitive learning outcomes of the control and experimental groups irrespective of the instructional methodology, as determined by a pre/post-test declarative knowledge cognitive instrument.

4. There is no significant statistical difference between the procedural effectiveness of the control and experimental groups in successfully troubleshooting a defective electrical generating set irrespective of the instructional methodology, as determined by the subject selecting the proper failed component during a procedural performance examination.

5. There is no significant statistical difference between the procedural effectiveness of the control and experimental groups in troubleshooting a defective electrical generating set; irrespective of the instructional methodology, as determined by the time required to complete a procedural performance examination.

Design of the Study

As stated earlier, the Onan technical training staff, often erroneously assumed that trainees who understood systems and sub-systems of the equipment could also effectively troubleshoot complex equipment. Troubleshooting (or problem solving) is a complex process (Gagne, 1970). For service technicians to be cognizant of the steps used in troubleshooting a problem, and the several methods of troubleshooting available to them, they must first be introduced to these steps and methods. In this study the experimental group was shown

five troubleshooting methods that have been used by experts in the past in Onan factory schools; and where these methods might be employed in troubleshooting various systems of an electrical generating set. The methods were explained and discussed during the first lesson of the experimental course, and instructors further explained how to apply these methods during later classroom presentations. These methods were also stressed during the troubleshooting practice time before the procedural performance examination on Wednesday afternoon. A model of the study is shown in Figure 1.

Control Group	O1	X1	O2
Experimental Group	O1	X2	O2

Figure 1. Model of the Experimental Design.

The control group received the standard small products, gasoline, course material on the Emerald generator set (see Appendix F), and the experimental group received two additional lessons (see Appendix G.) These lessons were:

(1) Introduction to troubleshooting methods, in which the five troubleshooting methods were named and discussed with examples of where each method might best be used.

(2) An enhanced DC control lesson in which the problem space of the Emerald control, from Johnson's (1987) study, was explained (see Figure 2.) This explanation included the instructor covering what each pin on the control board was used for, and what indication the technician would see if the proper input or output was not available at that pin, (*e.g.* P1-3 means Pin 3 of Plug 1).

Before students in both the control and experimental groups were given the procedural effectiveness troubleshooting problem, they were given at least one troubleshooting exercise and encouraged to use their own troubleshooting style synthesized from their declarative knowledge base and the knowledge gained during the week.

Methods

This study was based on Johnson's (1987) research into the differences between expert and novice troubleshooters. He determined that there was a difference between experts and novices in regards to their declarative (what it is) and their procedural (how to do it) knowledge bases. Johnson hypothesized that if novices were taught (1) the methods experts used in solving complex technical troubleshooting problems, and (2) some of the procedures that the experts had developed for themselves, then the novices would be able to perform as well as the experts in those specific instances.

This study sought to compare the effectiveness and efficiency of trainees in the Onan small products gasoline course under two training curricula. One, the control group curriculum, was the in-place small products gasoline training course on the Emerald generator set. The other, the experimental group curriculum, was essentially the same as the control course curriculum with the addition of one lesson (the troubleshooting methods), and the substitution of a second lesson (the DC control). The lesson added for the experimental course was "Introduction to troubleshooting methods" which was presented to the experimental group on Monday morning after they completed the knowledge pre-test. This lesson described five differing troubleshooting methods that have been used successfully by technicians in Onan training classes, and where each of these methods might best be employed by this class of technicians. The second lesson was the substitution of a new version of the engine control lesson which added the use of the problem space map shown in Figure 2. The subjects were given the same information on the operation of the engine control as the control group, but the information they received in the lesson was enhanced because of the addition of the problem space map. The problem space map was used to show the experimental subjects how the parts of the engine control work together to make the engine crank and run, and the generator produce output voltage.

Figure 2. Emerald I Generator Set Control Problem Space.

Prior to the subjects in either class receiving any instruction on the Emerald generator set, each group was given the same pre-test (see Appendix D) to determine what knowledge they brought into the training arena. It was determined by statistical analysis that the two groups were not significantly different in their entry scores (see Appendix F.)

After all subjects had completed the pre-test, the test was reviewed and the questions on all but the troubleshooting methods were fully explained. The control group was told that at the end of the week they would be given the material on the troubleshooting methods so even if they did not learn the material during the course of instruction that they would still benefit from the lesson. The experimental group was told that the first lesson they received after a short break would be on the troubleshooting methods to be used in the course.

The procedural performance examination on Wednesday was the same for each group. In fact, the same generator set that Johnson had used in his 1987 study was used during this study. The connection between the control board and the J1 connector was disturbed at pin #2 (crank signal to the starter solenoid). With this signal disconnected, the starter motor would not turn over the engine, although the ignition, fuel pump circuits, and the generator field flash circuit were operating properly. Therefore, without the signal from J1-2, the generator set would not start. Johnson's experts had been able to easily solve the same problem when it was presented to them, and the novices had trouble defining the problem. Each team of two to three technicians was allowed to complete at least one troubleshooting problem on the generator set which they had been working with during the week before they were called in to the testing room one at a time. Each technician was told the same story about a customer who brought the generator set in for repair with a reported problem of, "The generator set will not run," which is typical of the problems seen by technicians in the field. They were also told that we did not get to ask the customer any more questions about the problem before he left, but it didn't matter because we knew that (technician's name) would be coming in today and he is an expert technician. All technicans were

provided with a standard set of tools, a meter, a service manual for the generator set, and a wiring / schematic diagram of the generator set. Those technicians in the experimental class were allowed to use their copy of the problem space diagram that had been covered in the engine control lesson. The time it took for the subject to complete the examination, and whether he determined the correct problem were written on a troubleshooting form with a number which listed the order of the technician in the testing process. There was a great deal of rivalry between the subjects in each group to pass the examination in the lowest amount of time. When the subject was finished with the examination, he was told how long it took him to complete the examination, and if he selected the correct solution, that he passed. He was also cautioned not to discuss the examination with the rest of the class.

Friday morning after the Warranty / Liability lesson and the parts department presentation, the subjects were given the post-test which had the same questions as the pre-test, but in a different random order (see Appendix E.) After all subjects had completed the post-test, it was reviewed, and all questions discussed. It was determined through statistical analysis that both groups were statistically different when they left the class. Their final knowledge scores and gain scores were not similar (see Appendix C).

Limitations of the Study

While every effort was made to assure validity of the results from the study, there are some limitations which must be acknowledged.

1. There was no attempt to randomly assign subjects to either the control or experimental group. The consistent mixture of expert and novice technicians in the Onan classes have, historically, provided heterogeneity. The students tend to be experienced in servicing mechanical problems and, as a group, semiskilled in servicing electrical and magnetic problems.

2. The five questions about troubleshooting in the "Pre-Post Knowledge Examination" instruments were assembled by the researcher from lesson on troubleshooting delivered to the experimental group, and added to the questions used by Johnson in his 1987 study.

Delimitations of the Study

1. The population of electrical generator set service technicians is a relatively small, but growing population. To achieve a truly random sample of Onan service technicians at two weeks of factory schools would require scheduling a total stopping of work on customer's equipment for that two week period so any and/or all of a dealer's technicians could attend the factory school(s).

2. The study was conducted in an industrial training facility. The results might not readily be generalized to vocational training schools.

3. To ensure traceability of results from this study to Johnson's (1987) study, he was contacted by telephone for permission to use the knowledge examinations from his study in the present study. This permission was readily given. Upon receipt of permission to utilize test instruments and problem space model, some of the questions in each domain area of the original exams were deleted until the total count, with troubleshooting questions added, was 50 questions. This was done to have a comprehensive instrument which the students could complete in one and one-half hours.

Significance of the Study

This study has the possibility of changing the direction of teaching taken by educators who are involved in teaching / training the next generation of electro-mechanical technicians who will maintain complex and computer-driven equipment. This type of equipment is seen more often in manufacturing plants as the roboticized / computer numerical

controlled (CNC) work station becomes more prevalent. The sector of industry in which the Onan Corporation is involved is also becoming more complex and more computerized. The generator sets and transfer switches which are being designed as the next generation of equipment meant to keep the Onan corporation ahead of the competition is forcing the service technician to learn newer and more complex equipment at a faster pace than ever before. The equipment is becoming more difficult for the average self-trained technician to troubleshoot and repair. More and more of the technicians who are attending the Onan factory schools are requesting "troubleshooting tips" to help them solve all the problems in the field, which is seen by the training staff as a request for a 'grocery list' of problems and solutions. Often the solution to their problem is in the service manual, but either the technician does not have a copy of the manual, or the technician opts to solve the problem from memory, and often ends up using the 'shotgun approach' when troubleshooting the customer's equipment. Many (over 35% in 1987) of the circuit boards returned under warranty repairs have been found to be working properly. This means that the technician does not understand the operation and troubleshooting procedure for the newer equipment in the field. This study will help the Onan corporation to develop training methods for both field and factory training courses and troubleshooting job aids which are hoped to assist the technician in determining the real cause of the problem. These job aids hopefully, will also help to reduce the number of good circuit boards returned to the factory on warranty claims.

This study will attempt to determine if teaching the declarative and procedural knowledge which expert technicians have available to them can change the effectiveness (ability to select the correct failed part) and efficiency (time to complete the repair action) of novice technicians. The main thrust of this study came from Drs. Richard Swanson and Ruth Thomas, University of Minnesota, who are very involved in the process of determining how problem solving takes place in the mind of the novice and expert. The material came from Dr. Scott Johnson, University of Illinois, who did his doctoral dissertation on the

differences in the procedural and declarative knowledge which experts and novices have available to them as they work through the process of solving a problem in an electric generator set (1987). If Johnson's study (1987) is correct, teaching novices how to troubleshoot (troubleshooting methods) and the process which experts use (procedure) in troubleshooting a failed generator set will make a difference in the efficiency and effectiveness of the novice technicians in troubleshooting the same generator set. If this proves correct, then the same process could be applied to other problem-solving professions.

Definitions of Terms

Big three. A troubleshooting method in which the technician evaluates a symptom and determines which of three possible sections, in the applicable level of specificity, would most likely cause the symptom.

CNC. Computer numeric controlled. This is the latest method of controlling robotic and programmable manufacturing workstations. In the Onan corporation, CNC machines perform many phases of the manufacturing and machining of materials from raw stock to subassembly components.

Consumer products. Onan electrical products which are designed for consumer use, rather than industrial use. These include recreational vehicle (RV) and marine generator sets, portable generator sets, and their associated electrical control products (switches, etc.).

Declarative knowledge. The facts, principles and concepts that an individual knows (Anderson, 1980, 1982).

Easy-Likely. A troubleshooting method in which the technician tries to solve a problem by considering possible solutions that are most common and easiest to check before considering solutions less common or more difficult to check.

Emerald generator set. The generator set presently sold by the Onan corporation for use in recreational vehicles. This is the first RV generator set to have a solid-state control circuit board instead of a relay-type control circuit.

Expert. For this study, a technician who has developed the knowledge and skills needed to troubleshoot Onan electrical generator sets at a level well above the general technician population.

Expertise. The skill and knowledge possessed by some humans that result in performances far above the norm (Harmon & King, 1985, p. 259).

Generator set. An electric generator driven by an internal combustion engine. There is a control section which monitors the operation of both the engine and the generator.

Grocery list. An inefficient method of troubleshooting in which the technician follows some sequence of checking and/or replacing parts, as opposed to superstitious knowledge. The replaced parts may not have any real relationship to the problem, but are suspected and changed because "when you change X, always change Y and Z."

Half-half. A troubleshooting method in which the technician attempts to find the cause of a problem in a system by dividing the system into two parts and checking for the correct indication at that point. This sequence is then continued, in the required direction, until the cause of the symptom or problem is discovered.

Hypothesis. A possible solution to a problem based upon previously acquired and interpreted information.

Knowledge acquisition process. The process of locating, collecting, and refining knowledge (Harmon & King, 1985, p. 262).

Mental model. The networks and patterns of related symbols used by a technician while working on a problem.

Novice. For this study, a technician who has less than six months of experience on generator sets and not more than six months of electric/electronic training.

Prime Power. Production of electricity by diesel, gasoline, or gas-powered electric generator sets in locations where there is no utility power available. This is on the opposite end of the spectrum from standby power, as the generator sets are operating all the time to provide a constant source of electricity to the customer.

Problem solving. The process by which one starts from an initial state and proceeds to search through a problem space in order to identify the sequence of operations or actions which will lead to a desired goal (Harmon & King, 1985, p. 264).

Problem space. The area to which the student limits his search for solutions to a stated problem.

Procedural knowledge. The skills an individual knows how to perform (Anderson, 1980; 1982).

Protocol. A description of the activities, ordered in time, in which a subject engages while performing a task (Hayes, 1981, p. 51).

RV. A vehicle used for vacations or trips which is usually self-contained, i.e. it has its own drinking water supply, kitchen, bath or shower facilities, sleeping quarters, sanitary grey/black water tank, heating system, and an electrical generating set

Quick checks. A troubleshooting method in which the technician, based on prior experience or training, quickly focus attention on the most significant aspects of a suspected problem.

Sequential troubleshooting. A troubleshooting method in which the technician follows a specified , ordered, and proven sequence of steps.

Shotgun approach. A troubleshooting method in which the troubleshooter replaces every component which might have anything to do with the problem at hand. The components are replaced haphazardly, as if a shotgun was shot at the equipment, and everything hit was replaced. This approach is used quite often by technicians who are working on a problem which is beyond their level of expertise, and are guessing at a solution to the problem.

Standby power. The production of electricity by diesel, gasoline or gas-powered electric generator sets when the utility power fails. In this instance, the generator sets only provide power to the customer when there is a problem with the primary source of power, the utility company.

Superstitious knowledge. A troubleshooting method in which the technician replaces all components which have, in past occurrences, seemed to be related to a similar problem or symptom, as opposed to some sequence used in the grocery list method.

Technical troubleshooting. The sub-process of problem solving that involves investigation of faults in a technical system through the generation and testing of hypotheses.

Outline of the Study

Chapter 2. Review of the literature. In this chapter, is documented some of the information about human memory and cognition, which will help to give insight into how the human mind needs to see information in order to make relational assumptions about that information. These relational assumptions will be needed for the troubleshooter to be able to manage the large amount of information necessary to

troubleshoot and repair modern electric generating sets. We will also investigate the literature on problem solving methods and models, which will help us to understand the processes used by humans in solving problems. The third section of this chapter is on the teaching and testing of troubleshooting behavior. In this section, we will investigate how to most effectively and efficiently transfer information from the instructor to the student, so that the student can use this new information to solve problems.

Chapter 3. Experimental design. In this chapter we will look at the method chosen for this experiment; the setting where the experiment was performed, and why it was important to the Onan corporation; the subjects of the study, and the selection process by which they were assigned to the control and experimental groups; the apparatus used in the experiment; the treatments used in the study; the instruments used to evaluate the subjects' declarative and procedural knowledge; the data collection processes; and the statistical design used to test the five hypotheses of the study.

Chapter 4. Presentation , analysis, and interpretation of the data. In this chapter the data received from the subjects with the pre-/post-test knowledge instrument and the procedural performance instrument will be presented. The methods used to analyze this data will be explained, and the analyzed data will be interpreted in reference to the five hypotheses of the study.

Chapter 5. Conclusions, recommendations, summary. In chapter five the outcomes of the study will be presented, along with recommendations for further research, and a summary of the study will be presented.

Chapter 2

Review of Related Literature

Problem solving behavior involves ideas, models of thinking, environmental issues, and past experiences coming together in the proper ratios and at the right point in time. Because of this, the literature reviewed for this study was divided into three areas. The first is basic human memory and cognition, and the theory of problem solving. The second is problem solving methods and models, one of which was presented in a study by Johnson (1987). The third and final part of the literature review involves teaching and testing of troubleshooting behavior.

General Human Behavior

To study problem solving by humans, some assumptions of general human behavior have to be made. First, human behavior is thought to have a purpose which causes the behavior. Behavior is determined by plans developed by an individual instead of being determined exclusively by the environment as proposed by the pure behaviorists. This viewpoint is supported by Miller, Galanter, and Pribram (1968) who suggest that humans determine their behavior by means of inherited, acquired, borrowed and shared plans. this point implies an "awareness of being aware of behavior" or "metacognition" which is a common starting point of problem solving behavior theories.

Secondly, human behavior is adapted by the environment. This point refers to the biology of the individual and that humans can change their behavioral response to a situation as the environment around the situation changes (Simon, 1981). Scribner (1984) observed this phenomenon while studying the behavior of dairy workers. Scribner noted that the problem solving plans utilized by the workers in loading orders into delivery cases changed as the order (situation) and the problem the workers were presented with changed. The behavioral changes were most evident when the changes resulted in a labor savings for the workers. That this is a learned response. Scribner noted that experienced workers were more readily able, than novices, to adapt to different orders and

presentations of available full and partial cases of milk products from which to fill the orders. Third, and lastly, human behavior reflects the environment. The environment an individual is in must be taken into account to understand a person's behavior. Since people can create new behavioral plans from old plans as conditions or problems change, they are able to adapt to a change in the environment. If we attempt to understand the behavior of individuals without taking their environment into account, incomplete and inaccurate information will result (Simon, 1981).

Human memory and cognition and problem solving theory. By trying to develop intelligent computer systems which can solve problems by inference from known data, scientists have learned a great deal about how humans solve problems. Simon (1981) determined that although the human brain has almost unlimited long term storage area, the movement of information into short term memory is what slows down the thinking process. This is primarily because short term memory cannot hold more than seven items (p. 75). If these seven items are, however, placed in memory as one 'chunk', they are more easily recalled. Experts are more adept at connecting or 'chunking' information than novices, and this is one of the reasons why they troubleshoot faster than novices; they can look at larger portions of the picture at one time than novices can.

Bourne, Dominowski, and Loftus (1979) determined that the first level of memory at which data is recognized as either new or familiar is in sensory memory (p. 8). There are five sensory memories, one for each of the five senses. This is a very volatile memory, and since information is continually being impressed upon these sensory memories, the individual must constantly be sifting information to decide what will be kept and what will be forgotten. Information in these sensory memories which is not "encoded" will be lost in approximately 1 second. After encoding, the data can be moved from sensory memory to short term memory. Short term memory, or working memory, is where all information processing is accomplished, *(i.e.*, mathematical calculations, re-ordering mental lists, selecting the best possible alternative for a problem solution on an electric genera-

tor set.) Short term memory is limited to the length of time which it will hold data without further processing. This time limit is approximately 15 to 20 seconds (Bourne, Dominowski, and Loftus,1979).

The most common form of processing in the short term memory is rehearsal. This is when the information is mentally repeated over and over. This processing performs two functions. The first is to prevent information loss; the second is to convert the information into a form compatible with long term memory. The main information repository is long term memory. This memory has virtually unlimited storage capacity with no known information loss time like sensory memory and short term memory. Bourne, Dominowski, and Loftus, (1979) divided long term memory into three sub-memories: episodic, semantic, and procedural. Episodic memory stores the *context of occurrence of facts*, how things happened. Semantic memory is where *the facts themselves* are stored without their time or place of acquisition. Procedural memory is where *skills* are stored, what you can do with facts. This, therefore, would be the the memory where problem solving strategies are stored.

Problem solving methods and models

Wickelgren (1974) looked at formal problems and their solutions. He defined formal problems as those problems having a problem state consisting of the following types of information:

Givens. Conditions or facts concerning the problem which are explained at the start of the problem (p. 11).

Operations. The actions you are allowed to perform on the givens or any expression derived from the givens by previous actions (p. 12).

Goals. The final solution of the problem (p. 13).

There may also be subgoals which will lead from the givens to the goals. The problem state, as defined by Wickelgren, is equivalent to the problem space in Johnson's study (1987) which Johnson defined as:

Initial condition. Condition in which the given or starting conditions are represented.

Goal condition. Condition in which the final goal condition is represented.

Intermediate goal conditions. Consisting of new conditions that are generated by applying an operator to a condition.

Operators. The moves that result in a change from one condition to the next. (p. 11).

Table 2

Characteristics of well-and ill-structured problems.

Well-structured problem	Ill-structured problem
Definite initial situation is given.; all components needed to produce the goal are contained in the initial problem situation.	Incomplete initial situation is given.
Definite goal situation to be achieved, what is desired, what conditions must exist for the problem to be considered solved are given.	Vague or unspecified goal; no specific situation that can be used as a target for problem solving activity is given.
Specified operators that can be used to transform the situation are given; information about means or tools or operations with which the problem can be solved are given; information about the conditions under which the problem must be solved are given; information about access to resources is given.	Incomplete or no information about means for solving the problem is given; problem solver must generate substantial amounts of the data needed to obtain a solution and determine how the materials are to be arranged.

Newell and Simon (1972) distinguish between well-defined and ill-defined problems, as shown in Table 2. Well-defined problems are ones where a test already exists that is performable with a relatively small amount of processing effort that will determine whether a proposed solution is indeed a solution. Ill-defined problems are ones for which no such test exists.

Most problems Onan service technicians are faced with in the field are ill-structured. The customer often has no idea of what the generator set does to produce electricity, so the work ticket has a statement like, "generator set doesn't work." Does this mean that the generator set engine doesn't crank over, start, or run? Does this mean that the engine does start, but when the customer lets go of the start button the generator set stops? Does this mean that the generator set starts and runs but does not produce any voltage, or if there is some, not a sufficient value of voltage, or too much voltage? These are real concerns for the generator set technician who is considered to be the "expert" by the customer. When technicians begin to solve the problem with the customer's generator set, they must determine from visual, aural, and olfactory sense inputs what is correct and what is incorrect in the data received through these sensory inputs. After the technicians have determined what the real problem is on the equipment, they can begin to delimit their search area to the proper problem space, and work toward a solution to the problem.

A solution to a problem, according to Wickelgren, consists of four parts. They are:

(1) Complete specification of the givens.

(2) Complete specification of the operations to be used.

(3) Complete specification of the goals.

(4) An ordered sequence of problem states starting with the givens and terminating with a goal state (p. 16).

Wickelgren discussed three types of action sequences that people use in going from givens to goals. They are random trial and error, systematic trial and error, and classificatory trial and error

(p. 47). Random trial and error is equivalent to random sampling with replacement, and can be either a very short or very long process depending on the number of possible solutions and when the proper solution is selected from all possible solutions. Systematic trial and error is equivalent to random sampling without replacement. In this method of problem solving, the solutions which have been tried already are noted and not tried again. The final method, classificatory trial and error starts with the classification of all action sequences into equivalent classes. If one sequence within a given class will solve the problem, all other sequences in that class will also solve the problem. Conversely, if one sequence can be shown to be an incorrect solution, all other sequences in that class will also fail to solve the problem.

Strategies Used by Troubleshooters. Troubleshooters have many different and varied strategies for approaching and solving problems. One of the factors affecting the method chosen to attempt to solve the problem is how critical the problem appears to the troubleshooter. If the problem is a life and death situation, the troubleshooter may choose a different strategy than if there seems to be no need for undue haste in arriving at the final solution. Once experts have determined what two or three or four critical factors are required for correct equipment operation, they can check for those factors, and confine their search strategy to the most affected areas of the equipment. In this way, experts are able to solve problems faster than novices when the experts pick the correct search strategy.

Thomas and Litowitz (1986) reported on a study on problem solving which suggests that novice troubleshooters may try to apply all former hypotheses tried on similar problems to each new problem (the shotgun approach) until either all known possible solutions are exhausted, or the problem is solved.

Johnson (1987) suggested that students write down their steps as they performed them to keep track of where they had looked for the problem, and where the problem might still be. Wick-

elgren also stated that paper and pencil should be used extensively when solving problems so you can remember which sequences of solution steps you have tried. Loupe (1972) found that when trainees verbalized their possible solutions to a problem that the trainees were better able to associate the possible solutions with related information and develop more creative thinking patterns (p. 8). Often students in Onan schools report that when they are stumped on a problem in the field, they either call someone at their dealership, or just talk the problem over with themselves. This helps them to see where the problem might be, how to isolate it, and find the proper solution.

Differences Between Expert And Novice Troubleshooters. Johnson (1987) studied the differences between expert and novice troubleshooters to find what "tools" these two groups of troubleshooters had at their disposal to solve problems. Johnson found that since the experts had been working as troubleshooters for a longer period of time, they had a larger repertoire of experiences from which to draw in evaluating the present problem. The experts also had a mindset of, "It isn't usually a mechanical problem." In Johnson's research with experts and novices, the experts solved an electrical problem faster than the novices. When faced with a mechanical problem, the novices fared as well as the experts, since the novices could use unstructured sensory inputs as well as the experts.

Chi, Glaser, and Rees (1982) stated that the level of experience of the problem solver and the extent of their knowledge base is of prime importance when trying to solve high-level problems (p. 11). Johnson (1987) reported that experts had a larger repertoire of experiences as well as tried solutions, both those which succeeded and those which failed. Bransford (1979) stated that one large difference between experts and non-experts in problem solving is the level of knowledge about the area in question. Novices are more concerned with surface indications (symptoms) than the actual problem which caused the indication. Experts, on the other hand, are more familiar with actual equipment operation, and can often interpret the indications (symptoms) faster and more

accurately than novices (Johnson, 1987). Experts store information in larger sections or "chunks", and novices are more apt to store information as discrete facts which may or may not be associated with other facts and data which are relevant.

Bransford and Stein (1984) developed the "IDEAL" problem solving model which consists of the following steps:

(1) Identify the problem.
(2) Define and represent the problem.
(3) Explore possible strategies.
(4) Act on the strategies.
(5) Look back and evaluate the effects of your activities (p. 12).

The material in the systematic method of troubleshooting, presented during the experimental group training curriculum, conformed to the model presented above by Bransford and Stein (1984).

Kaufmann (1979) stated that imagery is strongly related to multidimensional problem solving abilities, or parallel information processing. Visual imagery is important in developing a parallel processing ability which allows you to look at more than one part of a problem at a time. This is a more intuitive problem solving process than a sequential process.

Whimbey and Lochhead (1979) found five areas where problem solvers fail to get the correct solution to a problem.

(1) Inaccuracy in reading the problem.
(2) Inaccuracy in thinking the problem through.
(3) Weakness in problem analysis, and solving the problem in an inactive manner.
(4) Lack of perseverance.
(5) Failure to think aloud.

They also stated five methods of good problem solvers.

(1) Positive attitude.

(2) Concern for accuracy.

(3) Breaking the problem into parts.

(4) Avoiding guessing.

(5) Activeness in the problem solving process.

Troubleshooting is associated with the application through evaluation levels of Bloom's (1956) cognitive taxonomy of educational objectives (see Table 3,) and is considered a higher order thinking skill. There are many definitions for what comprises a higher order thinking skill.

Table 3.
Blooms taxonomy of educational objectives.

Level	Example
Evaluation	Justifies sequence of a problem solution.
Synthesis	Uses Ohm's and Watt's Laws in power factor problem.
Analysis	Discerns need to use Ohm's Law.
Application	Given a problem, uses Ohm's Law correctly.
Comprehension	Explains Ohm's Law.
Knowledge	Knows Ohm's Law formula.

Quellmalz (1985) said that when students engage in purposeful, extended lines of thought during which they:

1) identify the type of problem presented

2) define the elements and terms used in the problem

3) evaluate and link relevant bits of information, and

4) determine the adequacy of information and procedures for drawing conclusions and/or solving problems,

then they are using the higher levels of Bloom's taxonomy of cognitive educational objectives to develop problem solving strategies. In addition, students engage in metacognition which involves

their becoming critical of the strategies they use, becoming self-conscious about their thinking, and developing self-monitoring, problem-solving strategies. In order for students to get to the application, analysis, synthesis, and evaluation levels of the cognitive taxonomy they must first pass through, and be conversant with, the knowledge and comprehension levels of the material being taught. Developing training materials which adults will consider relevant to their job as well as test them in the application through evaluation levels in Bloom's taxonomy is often difficult. The development of useful training materials and job aids for adults, which will help them to function in the troubleshooting (application through evaluation) levels of Bloom's taxonomy requires the developer to evaluate the material to be presented to the student and select only 'need-to-know' information. In order to determine how to perform this feat, we must consider the analysis, design, and development of training materials.

Teaching and Testing of Troubleshooting Behavior

This section covers four ideas on teaching and measurement of troubleshooting knowledge and behavior. Swanson and Gradous's (1986) system for the design, development, and delivery of troubleshooting training was used in the development of the experimental training curriculum. This was done to ensure that the subjects knew of the five troubleshooting methods that have been observed in use by experts at Onan. Beaudin (1987) said the trainer has to look beyond the sterile environment of the classroom/lab to the real-world environment in which the trainee will have to perform. By visiting the trainees at their place of work after the training, the instructor can reinforce those behaviors that can be used in that environment, and will have more examples for future classes. Since this was not possible, many examples from previous students' workshop problems were discussed during break times to help strengthen the subjects' positive attitude. Mager (1968) told us that for trainees to accept the information from the class and apply it in their work place, they must have a positive attitude. To help develop this attitude, the instructor must model the proper

behaviors. Mager (1973) discussed types of measurement of trainee performance. In this study, criterion-based measurement was used instead of norm-referenced measurement. This was done to see if each subject, individually, could perform the required behaviors on their own.

Swanson and Gradous (1986) developed a Training Technology System for the development of training materials and assessment of the training effort. Their system consists of five separate, but connected parts: analysis, design, development, application, and evaluation of the training program. This system was utilized in the development of the "troubleshooting methods" lesson which formed the core of the difference in training between the control group and the experimental group.

Beaudin (1987) stated that the teaching of a skill is the hardest part of any training program. If the trainer will look at the work environment in which the learner has to perform, then the training can be developed to improve job-related behavior. Also, after-training concerns, such as variables that cannot be simulated in the classroom should be addressed in the training. Since the researcher was not able to visit the trainees after the experimental class, many examples from previous classes were discussed during breaks to show the subjects that other service technicians had overcome some of the common problems with the Emerald generator set. If the trainer can visit the trainees on the job after the training , the trainees can get reinforcement of the behaviors covered in the training.

Mager (1968) discussed that teachers teach because they want to influence the capabilities of the trainee in the future. For trainees to remember the training after it has been experienced, the trainee must develop a positive attitude toward the training. That the trainee has developed a positive attitude can only be determined by the trainee's behavior. If the trainee exhibits "approach tendencies" toward the subject, the trainee is showing positive behavior, and may have developed a positive attitude toward the subject. If the trainee exhibits "avoidance tendencies", the trainee is

showing negative behavior, and has probably developed a negative attitude toward the subject. One way to get the trainees to perform as desired is to model the proper behavior for them. As the trainees see the proper behavior being modeled for them, they are more likely to develop the proper behaviors themselves.

Mager (1973) talked about measurement, evaluation, and tests. Measurement is a process of determining the extent of some characteristic associated with some object or person. Evaluation is the act of comparing a measurement with a standard and passing judgment on the comparison. A test is a way of measuring some desired characteristic (p. 8). Criterion-referenced measurement is when the trainees measurement results are compared against a standard. Norm-referenced measurement is when the trainees measurement results are compared with the results of the other trainees and a judgment of each trainee's score is made based on the results of the comparison. Criterion-referenced measurement was used in this study to see if the subjects could solve the problem (criterion), and not if they could all get the same time score on the performance examination or knowledge examination.

Summary

In this chapter, the background literature in human behavior and cognition was discussed. short term memory was determined to be the most important part of human memory for problem solving because it is there that the problem solving processes take place. Since short term memory can only hold a maximum of seven items, it was shown for more information to be accessible to the novice troubleshooter, the novice must write information on paper to have the same effect as the expert troubleshooter's chunking of information. Long term memory was determined to be the repository for past problem solving strategies or plans, both successful and unsuccessful. One of the largest stumbling blocks of novice problem solvers was determined to be their lack of past experiences from which to develop a troubleshooting schema; another is that they often still are lacking

metacognition skills. In the section on problem solving processes and models it was determined that for a problem to be a formal problem, it must possess several types of information. These are: givens, operations, and goals, either sub-goals or final goals. It was also stated that most of the problems which the subject students are asked to repair in real life are non-formal problems which are ill-structured problems. In the third section, on the teaching and testing of troubleshooting behavior, the design and application of knowledge and performance tests was discussed. Also in this section it was determined that a competency-based test is more objective than a norm-referenced test, especially for troubleshooting behaviors. A competency-based instrument was used as the procedural performance examination instead of a norm-referenced examination to determine if the subjects could isolate the problem to the correct failed part. It was felt that a norm-based examination would more readily determine class standing of the subjects as troubleshooters and, not determine their competence to solve the problem.

Chapter 3

Experimental Design

The purpose of this chapter is to explain the procedures which were used to conduct a test of a proposed troubleshooting training model, and compare the results of this model to the present model being used in the Onan Service Training Schools. The chapter includes the method used in this study, the setting for the study, information on the subjects and the manner in which they were selected for participation in the study, the apparatus used in the study, a discussion of the treatments and instruments used in measuring the learning outcomes, data collection procedures, and the statistical design used to test the hypotheses. It closes with a brief summary of the material covered.

Table 4.
Treatments and evaluation methods used in this study

GROUP	TREATMENT	EVALUATION METHOD
Control	In-Place Troubleshooting Treatment	Declarative Knowledge Pre-Test / Post-Test Procedural Performance Examination
Experimental	Experimental Troubleshooting Treatment	Declarative Knowledge Pre-Test / Post-Test Procedural Performance Examination

Method

This study was divided into two parts, developing the training program with the knowledge and performance test instruments, and conducting the experiment with the control and treatment groups. The design of the study is set forth in Table 4. Two groups of

students registered for a small products, gasoline powered generator set course at the Onan technical training facility were administered the pre / post knowledge examination, and the procedural performance examination, and were treated as independent groups. The researcher conducted a two-way analysis of variance on the declarative knowledge pre-test and post-test scores of the two groups. A two-way analysis of variance was used to compare both pre-test scores and the control group post-test score against the experimental group post-test score. A Scheffe' post-hoc test was performed on the outcome of the analysis of variance results to determine whether there were significant differences in declarative knowledge learning outcomes of the two groups. The researcher also conducted a t-test on the scores of the procedural performance examinations from the two groups, and the time to complete the performance examination to determine whether there were significant statistical differences in the procedural performance outcomes and procedural knowledge learning outcomes of the two groups.

Developing the training program. Development of the training and test instruments was begun by discussing the experiment and troubleshooting theory and practice with Allen C. Jacobson, Manager of the technical training department of Onan Corporation, where the study was to take place. He stated that he has seen trainees use five major methods of troubleshooting electrical and mechanical apparatus in his nine years at Onan. These methods are: Quick checks, Big-three, Half-half, Easy-likely, and Systematic. Definitions and examples of each method are listed in Table 5. These five methods were supported by Hewes (1978).

The second part of developing the training and testing for this troubleshooting study was to contact subject matter experts at the Onan factory who repair units in the factory production area which have failed final testing. These experts were asked what quick checks they would use to troubleshoot a failed Emerald electrical generator set, and their responses were used to develop the Quick Checks troubleshooting method information sheet for the

experimental group. Their responses for the question, "What checks do you perform to test a failed Emerald generator set?" are shown in Table 6. The "quick checks" troubleshooting method sheet can be found in Appendix (G).

Table 5.

Troubleshooting methods used by expert troubleshooters in Onan schools, and taught in the experimental course curriculum.

Method	Definition	Example
Quick Checks	Troubleshooting steps which can be performed quickly without tools.	Try to start the generator set.
Big Three	Three-part decision matrix for the generator set. Can also be applied to each part of the generator set.	Is the problem in the engine, generator, or the control?
Easy-Likely	The easiest to check and most likely to happen failures are tried as solutions before the harder to check and less likely to fail items.	Check for oil and gasoline before disassembling the engine.
Half-Half	The problem space is divided into two parts and the technician looks for the proper indication at that point. A proper indication means that the problem is between the other end of the problem space and the point tested.	Check for gasoline at the carburetor by loosening the line fitting and cranking the engine over.
Systematic	A combination of the above methods and troubleshooting charts in the service manual.	Using a sequential test procedure to efficiently and effectively find a solution to the problem.

Table 6.

Subject matter expert responses used to develop Emerald generator set troubleshooting "quick checks" method.

Expert #	Responses in order of application	
1	A.	Check the oil to make sure there is oil, and to see what quality oil was used by the customer.
	B.	Try to start the engine to determine if the control is good or bad.
	C.	If the engine starts, let it warm up and put a load on the generator to see if the generator set can produce the proper amount of power.
	D.	Try to stop the engine with the start/stop switch to check the control.
2	A.	Try to start the set.
	B.	Check the output voltage at no-load to see if the transformer regulator is set properly.
	C.	Put a full load on the set to make sure that it operates properly.
	D.	Check the output voltage and frequency at full load condition to make sure the set is providing full power to the customer.

Setting. The study was conducted at the Onan Technical Training facilities in Brooklyn Park, Minnesota, and covered two separate classes of students enrolled in the Small Products Courses. The control group was enrolled during the week of February 22-26, 1988, and the experimental group was enrolled during the week of March 14-18, 1988. The electrical generating sets were divided into product lines by application, generator capacity, and type of fuel. The specific courses used for this study fell into the small products gasoline area.

This study was undertaken to determine if there was a way of training technicians to troubleshoot more effectively in the Onan factory schools. The recreational vehicle (RV) generator set business, at the time of this study, was the major part of Onan corporation's gross income. Since the Onan corporation sold approximately 80 percent of the RV generator sets in the United States and Canada, the outcome of this study could have a great influence on the RV service industry in North America. When the Emerald generator set, with its

new circuit-board type control, first replaced the older BFA and NH style RV generator sets, the control board was not as reliable as it could have been. The technicians started to replace the control board because they either could not or did not want to take the time to troubleshoot the problem to the proper failure. After the quality of the circuit boards was increased, the technicians still replaced the circuit boards with alarming regularity. In one calendar year, over 54 percent of the Emerald circuit boards returned with warranty claims were tested as good on Onan's computerized testing stations. The company wanted to determine if the problem was with technician training, or if it was a non-training problem.

Subjects. Two classes of students for the small products, gasoline, training course at Onan Corporation were selected as test subjects. No attempt was made to randomly assign subjects to a class from those applying to the courses. In past experience at Onan, and as is stated in Johnson's study (1987), the students in all classes vary greatly in their backgrounds and experience levels. To evaluate experience and education level, a questionnaire was sent to all service technicians enrolled in Onan Corporation's Small Products Training Courses in the winter and spring of 1988 (see Appendix A). Averages of the responses from these two groups and Johnson's (1987) Experts and Novices are shown in Table 7. The students in the two classes used in this study averaged 24.5 months of generator experience. For electrical experience, the classes averaged 52.1 months of experience. In the engine area, the classes averaged 110.2 months of experience. The education for the two classes averaged 3.4 months (see Appendix C). Johnson (1987) published figures comparable to these, as shown in Table 7. As in Johnson's (1987) study of experts and novices, the two classes were expected to have a moderate to high level of expertise, and be closer together in their level of experience than in some previous studies. This was because the subjects came from a small sector of the technicians involved in installing, servicing, troubleshooting, and repairing generator sets in the recreational vehicle market. The actual figures of the subjects background educational and experiential levels varied from 1 to 168 months in their present po-

sition; 0 to 144 months experience with generators; 0 to 360 months experience with engines; 0 to 300 months electrical / electronic work experience; and from 0 to 60 months vocational-technical schooling, and two students who had finished an electrical engineering program.

Table 7.

Subjects' experience levels (averaged by group) from this study and Johnson's (1987) study (figures are in months).

	Background education areas surveyed			
	Engines	Generators	Electrical	Other
Present Control Group	89	17	26	3
Present Experimental Group	132	32	79	7
Johnson's Experts Group	126	121	114	72
Johnson's Novices Group	63	6	24	2

Apparatus. The equipment used for this investigation were electric generator sets manufactured by Onan Corporation, Minneapolis, Minnesota. Electric generating sets are used to provide electrical power for many applications including prime power and standby systems for office buildings, boats, recreational vehicles, and contractor's job sites. The specific electric generator set used in this study, the same unit used in Johnson's (1987) study, was an Onan Emerald electrical generator set used in recreational vehicles, e.g., Winnebago, Fleetwood (see Figure 3). The Emerald is the most common generator set used in the recreational vehicle market at this time.

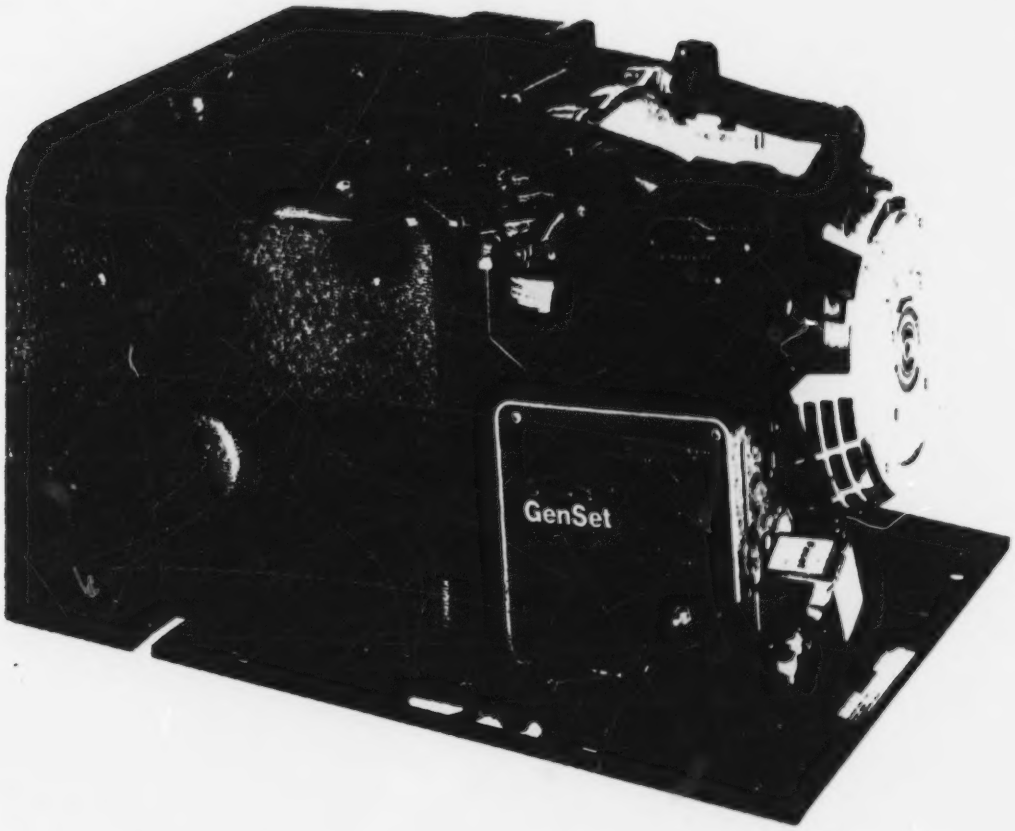

Figure 3. Onan Emerald I Generator Set

Treatments

The treatments used in this research project were very similar for the most part. The only two differences between the experimental group treatment and the control group treatment were the addition to the experimental curriculum of the introduction to troubleshooting methods lesson, and the use of the control problem space map during the control operation lesson. The major thrust of this experiment was to determine if subjects that were taught troubleshooting methods and a visual representation of the control operation sequence could troubleshoot a failed generator set more efficiently and effectively than subjects taught a more traditional course of instruction.

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00	Introductions Knowledge Pre-Test & Review Basic Electricity	Emerald Disassembly Engine Evaluation & Measurement	Reassemble Emeralds Control Operation	Disassemble BFA / NH sets BFA & NH Control	Warranty / Liability Parts presentation Final Troubleshooting & clean-up
12:00	Lunch Model/Spec & Safety Disassemble Emerald sets	Lunch Generators Reassemble Emeralds	Lunch Test & adjust Troubleshooting & Performance test	Lunch Reassemble BFA / NH Sets Test & Adjust Troubleshooting	Graduation Lunch Factory tour
4:00	Homework	Homework	Homework	Homework	

Figure 4. Control group treatment curriculum outline

Control Group Treatment. The control treatment was the in-place Small Products training curriculum at the Onan Technical Training facilities (see Appendix F). The control treatment covered the disassembly, measurement, reassembly, and testing of the Emerald generator set engine, control, and generator. In this treatment, it was assumed that if the students have knowledge of the operation of the generator set components (generator, control, and engine systems) they will understand how to troubleshoot the complete set. In this older curriculum, which is no longer used, the students were expected to create links between the systems of the generator set for themselves. A diagram of this treatment is shown in Figure 4. The subjects were given the knowledge pre-test, received the standard instructional treatment for the course of instruction, and were given both the knowledge post-test and procedural performance examination.

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00	Introductions Knowledge Pre-Test & Review **Troubleshooting Methods** Basic electricity	Emerald Disassembly Engine Evaluation & Measurement	Reassemble Emeralds **Control Operation with Problem Space Diagram**	Disassemble BFA / NH sets BFA & NH control	Warranty & Liability Parts Presentation Final trouble-shooting & clean-up
12:00	Lunch Model/Spec & Safety Disassemble Emerald sets	Lunch Generators Reassemble Emeralds	Lunch Test & adjust Troubleshooting & Performance Test	Lunch Reassemble BFA / NH sets Test & Adjust Troubleshooting	Graduation Lunch Factory tour
4:00	Homework	Homework	Homework	Homework	

Figure 5. Experimental group treatment curriculum outline, with added lessons in boldface.

Experimental Group Treatment. The experimental treatment covered the disassembly, measurement, reassembly, and testing of the Emerald generator set engine, control, and generator, as in the control treatment. In this treatment, it was not assumed that if the students have knowledge of the operation of the generator set components they will understand how to troubleshoot the set, as was the assumption with the control group treatment. A diagram of this treatment is shown in Figure 5. The subjects in the experimental group were given the same knowledge pre-test as the control group. The two additions to the experimental treatment were (1) specific instruction on troubleshooting methods used by expert troubleshooters, and these subjects were shown where these methods might best be employed; (2) the control problem space map to help them visualize the operation of the control system, and link the control components to the schematic and wiring diagrams which they will have to use in the field. At the same time during the week, the experimental group

received the procedural performance examination, and at the end of the week they received the knowledge post-test examination. The results of these examinations were compared to the control group scores to determine if there were any significant statistical differences between the two groups.

The additions, beyond the control treatment, to the experimental treatment were designed around the various methods used by expert troubleshooters to determine the actual cause of a problem in an electrical generator set. This study utilized the three areas which were delineated as important for improved technical instruction in Johnson's study (1987):

1) Defined content domain.
2) Domain-specific content in the instruction process.
3) Realistic learning experiences.

The first of two added lessons in the experimental treatment was the explanation of the five methods of troubleshooting seen most often in Onan factory schools. These are: quick checks, the big three, easy-likely, half-half, and systematic troubleshooting. These methods were previously explained in Table 5. Handout sheets for these methods can be found in Appendix (G). The rationale behind each of these troubleshooting methods was explained to the students, and several places to use each of the methods were explored in an exercise of stepping through the process of troubleshooting a failed generator set. During this lesson the students were told that the instructors would try to show how they would apply these five troubleshooting methods as the week progressed. The instructors would do this by stressing when they would apply a certain troubleshooting method, in the development of a lesson, and why they would choose that method on the problem at hand.

The second of two lessons added to the experimental treatment was based on the problem space diagram used by Johnson (1987), to show the steps of novice and expert troubleshooters in the problem space while in the process of solving a problem on an Emerald generator set. This lesson used an adapted version of the problem space for the Emerald

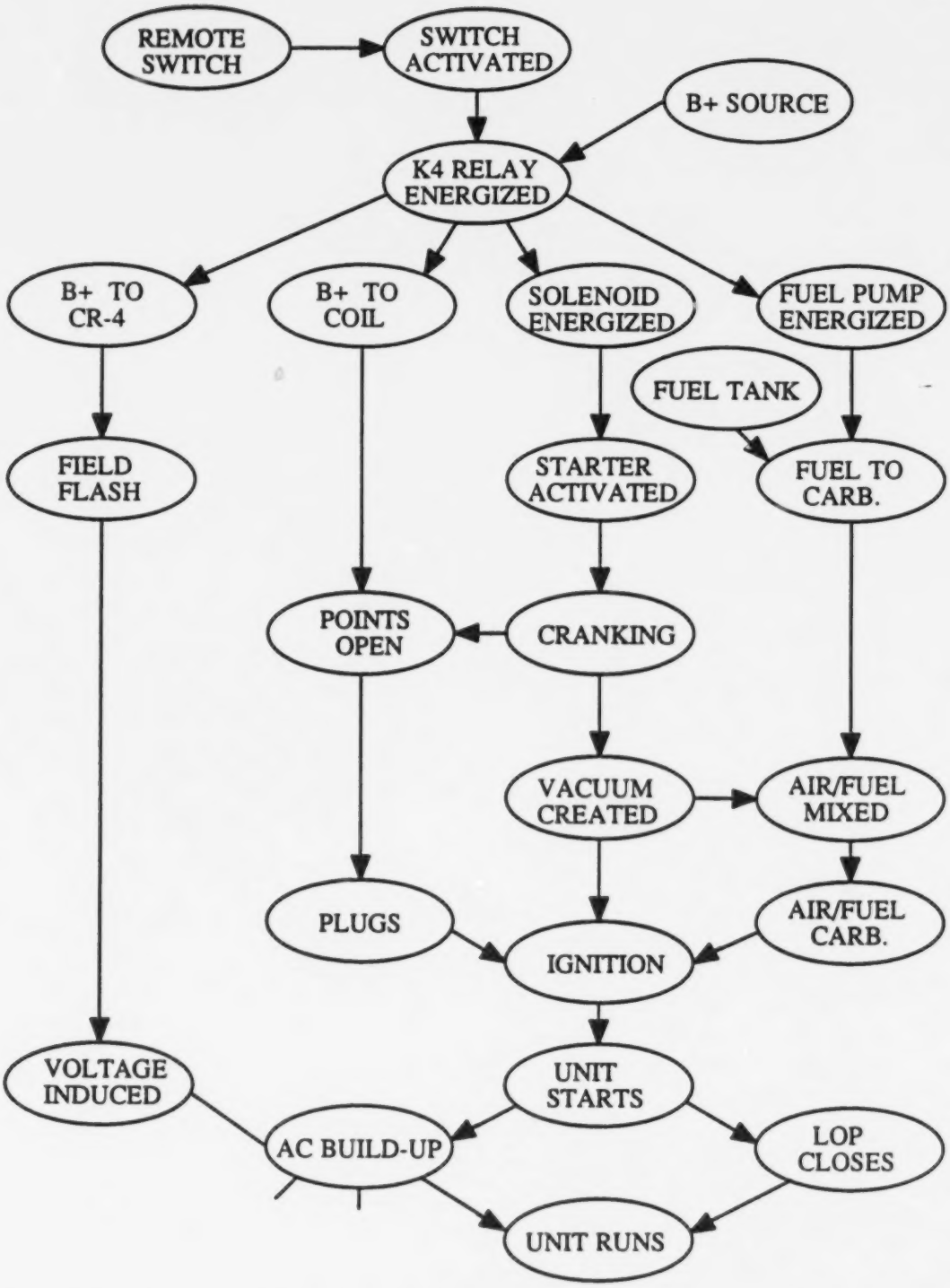

Figure 6. Emerald start and run circuit diagram used in this study, adapted from Johnson's study (1987),used by permission.

control circuits, modified from Johnson's diagram with his permission (see Figure 6) to diagram the interaction of the control circuits. During the Emerald control operation class the Emerald start and run circuit diagram was displayed on a white board at the front of the room, and as the instructor traced the start, run, and stop circuits within the Emerald control schematic diagram, the applicable portions of the Start and Run Circuit Diagram were highlighted. The connections between the Emerald control circuit board and the generator set wiring harness were emphasized at this time as the point at which over 50% of the problems with the Emerald control occur.

Test Instruments

The evaluation of the students' progress at the end of the course of instruction was performed in two ways: (1) a declarative knowledge post-test examination to determine if the students had a grasp of troubleshooting at the comprehension level of the cognitive domain; and (2) a procedural performance examination to determine if they could apply the troubleshooting and electrical generator set knowledge from the course. To ensure traceability of results from this study to Johnson's (1987) study, he was contacted by telephone for permission to use the knowledge examinations from his study in the present study. This permission was readily given. Upon receipt of permission to utilize test instruments and problem space model, some of the questions in each domain area of the original exams were deleted until the total count, with troubleshooting questions added, was 50 questions. This was done to have a comprehensive instrument which the students could complete in one and one-half hours.

It was the researcher's decision, supported by results of testing in the Onan factory school courses, that the trainees could complete this many questions in one and one-half hours at the beginning of the week. The questions were numbered and placed into a pre-test

(see Appendix D) and post-test (see Appendix E) format by the use of a random number table. Figures 4 and 5 showed the instruments and curricula used with the two groups.

A procedural performance examination sheet was originally designed to be filled out by the subject as a protocol of the subject's actions during the performance examination. This proved to be impractical with a group of 12 or 16 subjects. The indoctrination and training time for the subjects to use the sheet properly and with minimal impact on their troubleshooting process was determined to be greater in length than could be expended on the troubleshooting performance examination. Therefore, the researcher gave each subject the same indoctrination speech (see Appendix H) after the subject had entered the performance test room and the researcher wrote the subjects actions and electrical testing results on a procedural performance examination form. These sheets were coded with the sequence of the subject in the procedural testing of the group (one through 12 or one through 16), so the researcher could determine if there was any difference in the performance of the subjects as the testing period elapsed. Subjects were not given the procedural performance test in order of registration for the class, but rather were given the test after their work group had completed one or more troubleshooting exercises on the Emerald I generator set.

pre/post-test Declarative Knowledge Examination. The pre/post-test declarative knowledge examination was a 50-item multiple choice instrument based on Johnson's (1987) knowledge examinations and the troubleshooting methods used in the treatment course. This examination was administered as a pre / post-test instrument to both the experimental and control groups. The questions were divided into subject matter sections and the questions within these sections were put in order with a random number table. It was desired that the question order for the pre-test and post-test would be different to help eliminate test-retest error (See Appendices (D) and (E) for pre-test and post-tests respectively).

Procedural Performance Examination. The work-study performance examination was designed around the troubleshooting methods explained in the experimental class, and

the realistic learning experiences discussed in the summary chapter of Johnson's study (1987). The subjects were observed as they performed a troubleshooting exercise and their protocols were written down by the researcher (see Appendices (I), and (K)). This test was used to evaluate their procedural knowledge based on the effectiveness (correct solution found) and efficiency (time to completion) of their troubleshooting effort.

Data Collection

All subjects met together on the first day of scheduled class in each of the groups so that the nature of the study and the procedures necessary for collecting the data could be explained by the researcher. Opportunity was provided for any misunderstandings or concerns on the part of the subjects to be resolved. The researcher explained the instruments which were to be used to obtain data for the study of the two groups. These instruments were: (1) the pre-/ post-test declarative knowledge examination, and (2) the procedural performance examination. The subjects were informed that the pre-/ post-test declarative knowledge examination would be administered as a pre-test to obtain base line data. The scores obtained would reflect their knowledge of the Emerald generator set which would subsequently be improved by the course. These scores would not be used in a manner detrimental to the subjects, but would be compared with scores obtained at the post-test application of the instrument to determine cognitive learning outcomes (gain scores). The subjects were asked to complete the instrument to the best of their ability, and were told that it was not expected that they would be able to answer all of the questions. The tests were scored by the instructional personnel, and the data recorded.

Statistical Model. This study compared the differences in learning outcomes resulting from the use of the in-place Small Products curriculum of instruction at the Onan Service Training Factory School, and an experimental curriculum based on a study by Scott Johnson (1987) at the University of Minnesota. The subjects were tested using two different

methods to determine what effect their declarative knowledge factors and procedural knowledge factors had on their troubleshooting ability. These two methods were selected since troubleshooting of electrical generator sets is partly declarative knowledge and partly procedural knowledge. Declarative knowledge was evaluated by the pre/post-test declarative knowledge examination, and procedural knowledge was evaluated by use of a procedural performance examination (work sample).

Declarative Knowledge Testing. The analysis of variance was used to test the significance of differences between the means of the two groups for the pre/post-test declarative knowledge examination. The independent variable in this part of the study was the method of instruction to which the subjects were exposed. The dependent variable was the declarative knowledge outcome as evaluated by the pre/post-test declarative knowledge examination. The design of this study was comparative. Interest was directed toward the problem of identifying whether the different treatments resulted in significant differences in learning outcomes (declarative knowledge). The study used the two-way analysis of variance because the statistical model was designed to investigate if the pre-test and post-test scores of the control and treatment groups were related in any way. It would have been preferable to apply a two-factor factorial test to the data, but the groups were not identical in size. The researcher conducted a two-way analysis of variance test on the four parts of the pre/post-test declarative knowledge examination of the control and experimental groups, followed with a Scheffe' post hoc test to show whether there were significant interactions between the groups.

Procedural Knowledge Testing. The t-test was used to test the significance of the differences between the means of the two groups for the procedural performance examination. The independent variable in this part of the study was the method of instruction to which the subjects were exposed. The dependent variable was the procedural knowledge and performance outcome as evaluated by the procedural performance examination. The

design of this study was comparative. Interest was directed toward the problem of discovering whether the different treatments resulted in significant statistical differences in learning outcomes (procedural knowledge and performance).

Summary

In this chapter, an explanation of the experimental design of the study has been given. The setting for the study was defined as an electrical generator set manufacturer's technical training facility with between 12 and 16 students enrolled in most of the training courses conducted. The scope of training conducted in the courses offered at the facility was outlined. The background research for the study was explained. The population was defined as two classes of students enrolled in the small products, gasoline, school during the months of January (control) and February (experimental) of 1988. A discussion of the treatments was given which detailed the differences between the control course and the experimental course. In addition, the two test instruments: (1) "pre/post-test declarative knowledge examination" and, (2) "procedural performance examination" were explained and their use justified.

Chapter 4

Presentation, Analysis, and Interpretation of the data

This chapter presents the data gathered according to the methodology described in Chapter 3, and analyzes and interprets this data using the conceptual framework as a basis for discussion. Data collected in the implementation of the design of the study described in the preceding chapter were subjected to statistical analysis by either the Student's T test or the two-way analysis of variance to test the following hypotheses:

Basic Hypotheses

1. There is no significant statistical difference between the declarative knowledge pre-test scores of the control and experimental groups as determined by a pre-test declarative knowledge cognitive instrument.

2. There is no significant statistical difference between the declarative knowledge post-test scores of the control and experimental groups; irrespective of the instructional methodology, as determined by a post-test declarative knowledge cognitive instrument.

3. There is no significant statistical difference between the mean cognitive learning outcomes of the control and experimental groups irrespective of the instructional methodology, as determined by a pre/post-test declarative knowledge cognitive instrument.

4. There is no significant statistical difference between the procedural effectiveness of the control and experimental groups in successfully troubleshooting a defective electrical generating set; irrespective of the instructional methodology, as determined by the subject selecting the proper failed component during a procedural performance examination.

5. There is no significant statistical difference between the procedural effectiveness of the control and experimental groups in troubleshooting a defective electrical generating set; irrespective of the instructional methodology, as determined by the time required to complete a procedural performance examination.

Scores

The following raw scores in tabular form are in Appendix (C) as follows:

1. The raw scores, obtained from the pre/post-test declarative knowledge examination for the control and experimental groups.

2. The time scores and pass-fail marks obtained from the procedural performance examination for the control and experimental groups.

First Basic Hypothesis

It was hypothesized that there would be no significant statistical difference in the declarative knowledge levels as measured by pre-test scores between the control and experimental groups as determined by a declarative knowledge examination instrument. Table 8 is a comparison of the means and Student's T scores for the control and experimental groups; based on data obtained from the pre-test portion of the pre/post-test declarative knowledge examination.

Table 8.

Comparison of mean differences and t ratios of pre-test scores of control and experimental groups from the pre / post knowledge examination

Group	N	Mean	Variance	Critical t	Calculated t
Control	12	28.75	106.39		
Experimental	16	28.88	85.05		
Pooled	28	28.82	94.08	2.05	0.04
(Alpha= .05 / 27 df)					

The data (See Table 8) indicated there was no significant statistical difference in the pre-test scores for the two groups. A confidence level of .05 with 27 degrees of freedom was

established, requiring a t value of 2.05 to indicate a significant statistical difference in the pre-test scores of the groups compared. A calculated t value of 0.04 was obtained, which was less than the critical value of 2.05 with 27 degrees of freedom, indicating there was no statistically significant difference in the pre-test scores of the control and experimental groups.

Conclusion. The basic hypothesis of no significant statistical difference in the pre-test scores of the control and experimental groups; irrespective of the instructional methodology, as determined by the pre-test portion of the pre/post-test declarative knowledge examination was not rejected.

Second Basic Hypothesis

It was hypothesized that there would be no significant statistical difference between the declarative knowledge levels of the subjects in the control and experimental groups; irrespective of instructional methodology, as determined by a post-test cognitive instrument. Table 9 is a comparison of the means and t scores for the post-test scores of the control and experimental groups, based on data obtained from the post-test portion of the pre/post-declarative knowledge examination.

The data (See Table 9) indicated there was a statistical difference in the mean cognitive outcomes of the control and experimental groups. An Alpha level of .05 with 27 degrees of freedom was established, requiring a t value of 2.05 to indicate a significant statistical difference in the mean cognitive learning outcomes of the groups compared. A calculated t value of 68.38 was obtained, which was more than the critical value of 2.05 obtained at a confidence level of .05 with 27 degrees of freedom, indicating there was a significant statistical difference in the mean cognitive learning outcomes between the groups tested.

Table 9.

Comparison of mean differences and t ratios of post-test scores of control and experimental groups from the pre / post knowledge examination

Group	N	Mean	Variance	Critical t	Calculated t
Control	12	37	63.27		
experimental	16	40.75	67.8		
Pooled	28	39.14	65.89	2.05	68.38
(Alpha= .05 / 27 df)					

Conclusion. The basic hypothesis of no significant statistical difference in the post-test scores of the control and experimental groups; irrespective of the instructional methodology, as determined by the post-test portion of the pre/post-test declarative knowledge examination was rejected.

Third Basic Hypothesis

It was hypothesized that there would be no significant statistical difference between the mean cognitive learning outcomes of the control and experimental groups; irrespective of the instructional methodology, as determined by a pre/post- test declarative knowledge cognitive instrument. Table 10 shows the number of subjects in each group, the mean, standard deviation, error and confidence intervals for the Control and Experimental group Pre-Test and Post-Test scores. Table 11 shows the result of a two-way ANOVA on the control and experimental group pre-test and post-test scores, and Table 12 shows the results of a Scheffe' Test on the results of the two-way ANOVA.

The means, standard deviations, and confidence intervals for the pre-test and post-test scores of the control and experimental groups (See Table 11) indicated that there was a significant statistical difference between the pre-test and post-test scores of the control and

experimental groups. The data readily shows that the confidence intervals for the control group pre-test and post-test scores overlap, while the confidence intervals for the experimental group pre-test and post-test scores do not overlap. The lack of overlap between the experimental group pre-test and post-test scores more strongly indicates that these scores were taken from two different populations than were the control group scores; therefore, the experimental group learned something that the control group did not.

Table 10.

N, mean, standard deviation, error, and confidence intervals for control and experimental group pre-test and post-test scores.

Group	Count	Standard Mean	Standard Deviation	Error	95% Conf Int for Mean
Pre Cont	12	28.75	10.31	2.98	22.19 to 35.30
Post Cont	12	37.00	7.95	2.29	31.94 to 42.05
Pre Experi	16	28.88	9.22	2.31	23.96 to 33.79
Post Experi	16	40.75	8.23	2.06	36.36 to 45.14
Total	56	33.98	10.22	1.37	31.24 to 36.72

Group	Minimum	Maximum
Pre Cont	14	48
Post Cont	23	46
Pre Experi	10	43
Post Experi	18	50
Total	10	50

A confidence level of .05 with 55 degrees of freedom was established, requiring an F value of less than 6.62 to indicate a significant statistical difference in the mean cognitive learning outcome of the groups compared. A calculated P value of 0.0007 was obtained, which was less than the critical F value of 6.62 obtained at a confidence level of .05 with 55 degrees of freedom, indicating there was a significant statistical difference in the mean cognitive learning outcomes between the groups tested.

Table 11.

ANOVA of control and experimental group pre-test and post-test scores.

Source	df	Sums of Squares	Mean Squares	F Ratio	P Ratio
Between Groups	3	1587.98	529.32	6.62	.0007
Within Groups	52	4159.00	79.98		
Total	55	5746.98			

The Scheffe test on the outcome of the two-way ANOVA on the pre-test and post-test scores of the control and experimental groups (see Table 12) indicates the mean of the experimental group post-test is significantly different from the pre-test of both the control and experimental groups, but the control group post-test is not significantly different from either post-test. This post-hoc test verifies that the experimental group learned something that the control group did not learn.

Table 12.

Scheffe' procedure for anova on pre/post-test data for control and experimental groups.

Scheffe' Procedure Ranges for the .050 level - 4.09 4.09 4.09 (these are table ranges)
The value actually compared with Mean(J)-Mean(I) is...
6.3238 * Range * Sqrt(1/N(I) + 1/N(J))
(*) denotes pairs of groups significantly different at the .050 level.

Mean	Group	Pre Control	Pre Experimental	Post Control	Post Experimental
		Pre Control	Pre Experimental	Post Control	Post Experimental
28.75	Pre Control				
28.88	Pre Experimental				
37.0	Post Control				
40.75	Post Experimental	*	*		

Conclusion. The third basic hypothesis of no significant statistical difference in the mean cognitive learning outcomes between the control and experimental groups, as deter-

mined by the scores from the pre/post-test declarative knowledge cognitive instrument was rejected.

Fourth Basic Hypothesis

It was hypothesized that there would be no significant statistical difference between the procedural effectiveness (accuracy in selecting the correct failed component) of the control and experimental groups; irrespective of the instructional methodology, as determined by a procedural performance examination. Table 13 is a comparison of the pass/fail troubleshooting scores and t ratios from the procedural performance examination for the control and experimental groups. A confidence level of .05 with the appropriate degrees of freedom for each group compared, indicated that no statistically significant learning outcomes did occur.

Table 13.

Comparison of mean differences and t ratios of pass/fail troubleshooting scores from the procedural performance examination.

Group	N	Mean	Variance	Critical t	Calculated t
Control	12	0.67			
Experimental	16	0.69			
Pooled	28	0.68		2.05	0.54

The data (See Table 13 and Appendix C) indicated that if there would have been one more subject in either group that passed the procedural performance examination, the numbers would have been more explicit. As it happened, the number of subjects successfully passing the examination (eight of 11 in the control group, and 11 of 16 in the experimental group) are so close to two-thirds of the subjects in either group, that it is imprecise—even using Student's t because of the small number of subjects—to make a definitive statement either way. This indicated there was not a significant statistical difference in the effective-

ness of correct troubleshooting and selection of the proper failed part between the groups tested.

Conclusion. The fourth basic hypothesis of no statistically significant difference in the ability to successfully troubleshoot a failed Emerald generator set between the control and experimental groups, as determined by a procedural performance examination was not rejected.

Fifth Basic Hypothesis

It was hypothesized that there would be no significant statistical difference between the procedural effectiveness (time to troubleshoot a failed Emerald I generator set) of the control and experimental groups; irrespective of the instructional methodology, as determined by a procedural performance examination. Table 14 is a comparison of the troubleshooting time scores from the procedural performance examination for the control and experimental groups. Analysis of the data indicated that statistically significant differences in learning outcomes for the control and experimental groups did occur. The mean time for the experimental group troubleshooters to solve the problem was 9.13 minutes, and the mean time for the control group subjects was 12.83 minutes. This shows that the experimental group was, on the average, able to complete the procedural performance test more than 3.6 minutes faster than the control group.

Table 14.

Rank order of troubleshooting times for the procedural performance examination by group, showing the number of subjects with each troubleshooting time score.

Control ss	Time	Experimental ss

1	24	
	22	1
1	20	
1	15	1
2	14	
2	13	
	12	1
2	11	1
	10	2
	9	2
1	8	2
	7	1
1	6	1
1	5	3
	4	1
12.83	MEAN	9.13
11,13 ,14	MODE	5
13	MEDIAN	8.5

The data (See Table 14) indicated that there was a significant statistical difference in the means of the troubleshooting times needed by the Control and experimental group subjects.

Conclusion. The fifth basic hypothesis of no statistically significant difference in the mean time required to troubleshoot a failed Emerald generator set between the control and experimental groups, as determined by a procedural performance examination was rejected.

Summary

By use of the Students' t formula, it was determined that there was no significant statistical difference between the knowledge pre-test scores of the control and experimental groups, with means of 28.5 and 28.88 respectively. By use of the Students' t formula, it was determined that there was a significant statistical difference between the knowledge post-test scores of the control and experimental groups, with means on post-test scores of 37 and 40.75 respectively. By analysis of the knowledge pre-test and post-test data using a two-way ANOVA with a Scheffe' post-hoc test, it was determined that there was a significant statistical difference between the control and experimental groups. This difference was more

clearly defined by the confidence intervals for the pre-tests and post-tests for the two groups. The confidence intervals for the control group pre-test and post-test overlapped, and the confidence intervals for the experimental group pre-test and post-test did not overlap. This showed that the experimental group pre-test and post-test scores had a much greater probability of coming from different populations than did the control group pre-test and post-test scores. By analysis of the procedural performance test data(ability to select the correct failed part), and the use of the Students' t formula it was determined that there was no significant statistical difference between the procedural effectiveness of the control and experimental groups in their ability to select the correct failed part when troubleshooting an electric generator set. By analysis of the procedural performance test (time to select a failed part) data it was determined that there was a significant statistical difference in the procedural efficiency of the control and experimental groups in the time needed to troubleshoot an electric generator set.

The overall gain of knowledge from this study was that if novices are given information on troubleshooting methods (declarative knowledge on how experts *see* the electrical portion of the electrical generating set), and how to use this information (procedural knowledge), they will be able to solve a given problem faster than other novices not given this information.

Chapter 5

Conclusions, Recommendations, Summary

This study sought to compare the present Onan Service Training curriculum for service technicians of small gasoline-powered electrical generator sets with a curriculum based on a model developed by Johnson in his 1987 study of novices and experts.

Groups

Commonalties. These courses were taught at the Onan Service Training facility in Brooklyn Park, Minnesota, and utilized the same knowledge examinations, with the addition of questions on troubleshooting methods, used by Johnson in his 1987 study of expert and novice service technicians. The same electrical generator set used for troubleshooting tests in Johnson's 1987 study was also used to try to keep the number of variables between the original study and this follow-up to a minimum.

This study developed from the cooperative efforts of the University of Minnesota Training and Development Research Center, and the Onan Corporation Service Training Department, and was designed and tested during the period of December, 1987 to April, 1988, and covered two classes of the Small Products, Gasoline, course. This study utilized the Analysis of Variance and the F Test for the Pre / Post Knowledge Examination data; and the t-Test for the Procedural Performance Examination time and accuracy data.

The setting for this study was a private electrical generation and control corporation in Minneapolis, Minnesota and its suburbs. At the time of this study, Onan Corporation provided training to an average of 300 service technicians during approximately 20 weeks of the year in its Service Training facilities. Another 100 service technicians received technical instruction from Onan factory trainers in Onan Distributor's facilities throughout the year.

Control group. The control group received the in-place Onan curriculum with the pre/post-test (declarative knowledge) examination, and the procedural performance examination (work study). After completion of the procedural performance examination and the knowledge post-test , the control group was given the information on the five different troubleshooting methods.

Experimental group. The experimental group received the experimental lesson on the electrical generator set control operation, based on Johnson's study, with the pre/post-test (declarative knowledge) examination, the discussion of the five troubleshooting methods observed at Onan schools, and the procedural performance examination (work study) .

Conclusions

Hypothesis 1. There is no significant statistical difference between the declarative knowledge pre-test scores of the control and experimental groups as determined by a pre-test declarative knowledge cognitive instrument.

The analysis of the declarative knowledge pre-test data showed there was not a statistically significant difference between the control and experimental groups when they entered their respective weeks of school at the Onan Technical Training Facility.

Hypothesis 2. There is no significant statistical difference between the declarative knowledge post-test scores of the control and experimental groups; irrespective of the instructional methodology, as determined by a post-test declarative knowledge cognitive instrument.

The analysis of the declarative knowledge post-test data showed there was a statistically significant difference between the control and experimental groups when they completed their respective weeks of school at the Onan Technical Training Facility.

Hypothesis 3. There is no significant statistical difference between the mean cognitive learning outcomes of the control and experimental groups; irrespective of the instruc-

tional methodology, as determined by a pre/post-test declarative knowledge cognitive instrument.

The analysis of the means, standard deviation, and confidence intervals for the pre-test and post-test scores for the control and experimental groups showed that there was a significant difference between the overall outcomes of the two groups in the area of declarative knowledge. This was further highlighted by a two-way ANOVA of the pre-test and post-test scores of the two groups which produced a P score of .0007, showing that the two groups were from two different populations, as regarding total outcome in the area of declarative knowledge. A Scheffe' on the outcome of the two-way ANOVA showed that the experimental post-test mean differed significantly from both pre-test means, but the control group post-test mean did not. Although both groups had post-test means that were higher than their respective pre-test scores, the experimental group had a larger gain score.

Hypothesis 4. There is no significant statistical difference between the procedural effectiveness of the control and experimental groups in successfully troubleshooting a defective electrical generating set; irrespective of the instructional methodology, as determined by the subject selecting the proper failed component during a procedural performance examination.

The analysis of the procedural performance examination data related to correct selection of the failed part indicated that approximately two-thirds of each group (nine of 12 in the control group, and 11 of 16 in the experimental group) were able to correctly select the failed part. Since the difference between the groups was so insignificant, it was determined that in this area there was no difference. The effectiveness of the two groups at this point was the same.

Hypothesis 5. There is no significant statistical difference between the procedural efficiency of the control and experimental groups in troubleshooting a defective electrical

generating set; irrespective of the instructional methodology, as determined by the time required to complete a procedural performance examination.

The analysis of the procedural performance examination data related to time needed to complete the procedural performance examination was significantly different. The experimental group was able to complete the examination with a mean time of 9.13 minutes, and the control group took 12.83 minutes to complete the examination. The efficiency of the experimental group was better than the control group.

This difference of approximately three minutes may seem insignificant. In studies of technicians in later Onan schools, as the technicians "learned their way around" in troubleshooting electrical generator sets, their efficiency (speed of completion of problems) and their effectiveness (ability to select the correct failed part) both increased rapidly.

Recommendations

It is recommended that further research be conducted to investigate the following :

1. That the experiment be replicated using a Solomon 4-group experimental design wherein two of the four groups are given the same amount of data as the control and experimental groups in this study. Groups three and four would be given one part of the information given to the experimental group; one group would receive the troubleshooting methods, the other the map of the problem space. This would better determine if the troubleshooting methods (declarative knowledge) or the troubleshooting knowledge (procedural knowledge) had more influence on the ability of the experimental group to perform better in the procedural performance examination.

2. That the experiment be replicated with an equal number of subjects in each of the four groups to make data analysis much easier, and possibly more meaningful.

3. That the subjects in the experimental group given only the control problem space diagram be instructed on the information contained in the problem space map. The instruc-

tor then would be able to guide the group to develop the problem space diagram themselves. This could have great bearing on the outcome of the experiment.

4. If the subjects in the two groups which were given the problem space diagram were to develop the diagram with the help of the instructor as the control operation lesson was presented, instead of the instructor presenting it to them, would there be a change in the procedural effectiveness and efficiency difference between the two groups? This effectiveness and efficiency could be used to estimate the effect the troubleshooting methods lesson made in the performance of the groups.

5. To increase training effectiveness and efficiency with the least expenditure of time, the teaching of the five troubleshooting methods and a flowchart of the control used in the equipment has been included in the curriculum at Onan, and should be included in the curriculum at other electrical/electronic technical training facilities. This addition will give the students a more concrete representation of the processes used in the electrical/electronic equipment (flowchart); and a ready reference to different kinds of troubleshooting skills and their applications. Johnson's problem control space has been utilized as a teaching tool and job aid in the Onan classes on the Emerald generator set since the completion of this study. In addition, the concept of a "mind map" of the control operation has been extended to the other small (under 20 kilo Watt) generator set courses.

Similar troubleshooting job aids have been used in other areas, as shown in Thomas and Litowitz (1986), and Thomas and Englund (1990).

With careful observation of the material covered, and consistent size of chunks placed in each "problem control space," this method of teaching the declarative knowledge of experts might be used in many other fields of study where the initial quantity of choices is overwhelming to the novice. These might include human and veterinary medicine, auto mechanics, and computer repair.

Summary

This study determined that the differences between novices and experts in troubleshooting complex equipment are able to be overcome. Using the information and methods put forth by Johnson in his 1987 study of novice and expert troubleshooters, the researcher was able to verify that if novices are taught some of the methods that experts use to solve problems in complex equipment, and given a logical flow diagram of the equipment for operation and testing of the equipment, the novices can become experts on that equipment also. The experimental group had approximately the same mean score on the pre-test as the control group, but had a higher mean post-test score than the control group. In addition, the experimental group had a smaller mean time needed to solve the procedural performance examination than did the control group.

Since this study was performed, the technical training department of the Onan Corporation has developed several job aids for technicians working on the recreational vehicle and marine generator sets. After these job aids were distributed to the technicians, the percentage of functional control assemblies returned to the factory on warranty claims has dropped from 35% of all returned control assemblies to 10%. The technicians who are using the job aids are able to determine if the control assembly has failed faster and more accurately than those technicians not using the job aids. Onan Corporation is presently in the development stage for similar job aids for standby and prime power generator sets and electrical switchgear. These larger generator sets and switchgear are used in hospitals, prisons, domed stadiums, and similar facilities where the loss of electrical power for more than a few seconds can create an extremely critical situation.

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APPENDIX A

REGISTRATION QUESTIONNAIRE

REGISTRATION CONFIRMATION

WORKSHEET

Please complete this form and return it to Onan in the enclosed envelope at least two weeks prior to the beginning of training. This information will be used to help make your Onan training experience meet your specific needs. All information will remain confidential.

NAME: _____ _____
(last) (first)

EMPLOYER: _____

EMPLOYER'S ADDRESS: _____

PART 1: WORK EXPERIENCE:

A. Which best describes your present position? (If you work on more than one area, see the note below.)

_____ Service _____ Sales _____ Parts _____ Management _____ Other

NOTE: If your job includes more than one area, indicate by percent how much time you spend in each area. Example:

60% Service 20% Sales — Parts 20% Management — Other

B. How long have you been in your present position?

_____ Years _____ Months

C. Do you have any previous work experience with engine driven generators?*

_____ Years _____ Months _____ NONE

D. Do you have any previous work experience with engines and/or mechanics?*

_____ Years _____ Months _____ NONE

E. Do you have any previous work experience with electricity and/or electronics?*

_____ Years _____ Months _____ NONE

* Be sure to include any military work experience that applies.

PART 2: EDUCATION AND TRAINING:
Please describe any formal instruction you have received in electrical and/or mechanical subjects. Include the type of program and its approximate length.

A. VOCATIONAL SCHOOLS:
(Examples: Nine-month Evening Small Engine Program;
Two-year Diesel Program.)

_____
_____
_____
_____

B. MILITARY SCHOOLS:
(Examples: Four-month Power Generation Technician School;
Six-month Electronic Technician School.)

_____
_____
_____
_____

C. COLLEGE COURSES:
(Examples: One course in Beginning Electronics;
Two courses in Engine Systems.)

_____
_____
_____
_____

D. FACTORY TRAINING:
(Examples: Two-day Onan school at distributor;
One-week Briggs & Stratton Engine School.)

_____
_____
_____
_____

PART 3: YOUR GOALS AND EXPECTATIONS

A. Describe any special concerns or things you want to learn while attending an Onan factory training course.

_____
_____
_____
_____
_____
_____
_____
_____

THANK YOU!

APPENDIX B

RESEARCH CONSENT FORM

RESEARCH CONSENT FORM

You are invited to participate in a study of technical troubleshooting methods. We hope to learn how different ways of teaching troubleshooting affect the ways people attempt to solve technical problems.

If you decide to participate, you will be asked to troubleshoot a faulty generator set. The generator set will have a problem installed on it and you will be asked to locate the problem and correct it. While you work through the problem, you will be monitored by an instructor who will write down the troubleshooting steps you are taking, the tests you make, and the results of those tests.

You will also be asked to take a test on Monday before the Emerald course begins, and another test on Friday after the end of the Emerald course. Each of these tests will take you approximately an hour to complete.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

Your decision whether or not to participate will not change your relationship and training opportunities with the Onan Technical Training School. If you decide to participate, you are free to change your mind and be removed from the study at any time.

If you have any questions, please ask. If you have any questions in the future, you may reach me at (612) 574-8175.

Thank you,

Edward J. Westerdahl

You are making a decision whether or not to participate in this research study. Your signature indicates that you have read the above information and have decided to participate. You may decide to withdraw at any time without prejudice after signing this form should you choose to discontinue participation in this study.

_____ _____

Signature Date

Signature of Investigator _____

APPENDIX C

CONTROL AND EXPERIMENTAL GROUP
REGISTRATION AND EXAMINATION SCORES DATA

Table 15.

Control class registration data (listed in months)

SS#	Generator	Engine	Electrical	Education
C1	0	204	0	2
C2	4	96	0	0
C3	48	0	0	0
C4	76	156	76	0.14
C5	0	0	0	0
C6	0	4	60	0.75
C7	12	60	0	0
C8	0	0	0	0
C9	12	180	120	0
C10	0	144	0	0
C11	48	216	48	1.25
C12	0	6	6	1.5
Totals	200	1066	310	89.64
Mean	16.67	88.83	25.83	2.87

Table 16.

Control class examination scores

SS#	Pre-Test	Post-Test	Performance Mark	Performance Time
C1	22	37	1	13
C2	14	24	1	15
C3	30	46	0	8
C4	25	37	1	13
C5	17	23	0	24
C6	44	44	1	6
C7	34	44	1	14
C8	23	34	1	11
C9	26	36	1	14
C10	37	42	1	5
C11	25	31	1	20
C12	48	46	1	11
SUM	345	444	9	154
MEAN	28.75	37	0.75	12.83
SD	10.31	7.95	0.45	5.41

Table 17.

Experimental class registration data (listed in months)

SS#	Generator	Engine	Electrical	Education
E1	144	192	24	8.0667
E2	0	90	24	60.5
E3	0	180	12	96.5
E4	24	96	0	52.5
E5	24	36	24	1
E6	108	360	245	42.75
E7	0	0	0	0
E8	36	120	60	28.75
E9	60	120	0	0
E10	0	180	180	29
E11	24	60	60	24
E12	0	240	0	0
E13	42	42	42	0
E14	24	120	180	0
E15	0	36	300	4
E16	6	0	102	24
Total	486	1974	1175	387.25
Mean	30.38	123.38	73.44	6.04

Table 18.

Experimental Group Examination Scores

SS#	Pre-Test	Post-Test	Performance Mark	Performance Time
E1	43	48	0	10
E2	36	47	1	6
E3	43	50	1	9
E4	27	42	1	15
E5	24	36	1	10
E6	37	49	1	12
E7	20	36	0	8
E8	27	42	1	9
E9	22	33	0	4
E10	40	49	1	11
E11	22	34	1	22
E12	10	18	0	8
E13	23	42	0	7
E14	29	39	1	5
E15	34	46	1	5
E16	25	41	1	5
SUM	462	652	11	146
MEAN	28.88	40.75	0.69	9.13
SD	9.22	8.23	0.48	4.53

Table 19.

Pass/fail scores for the procedural performance examination.

Group	N	N Passing	N Failing	Passing Ratio
Control	12	9	3	9/12
Experimental	16	11	5	11/16

Table 20.

Rank order of troubleshooting times for the procedural performance examination by group, showing the number of subjects with each troubleshooting time score.

Control ss	Time	Experimental ss
1	24	
	22	1
1	20	
1	15	1
2	14	
2	13	
	12	1
2	11	1
	10	2
	9	2
1	8	2
	7	1
1	6	1
1	5	3
	4	1
12.83	MEAN	9.13
11,13 ,14	MODE	5
13	MEDIAN	8.5

APPENDIX D

DECLARATIVE KNOWLEDGE PRE-TEST AND ANSWER SHEET

EMERALD GENERATOR SET PRE-TEST

This test is designed to check your knowledge in the following eight areas:

1. Basic Magnetics area
2. Basic Electrical / Electronics area
3. Basic Mechanical area
4. The 4.0 BGE Emerald Control (Print #611-1174)
5. Ohm's Law
6. Using the BGE/L Service Manual
7. Using the BGE/L Parts Manual
8. Troubleshooting Methods

You will be provided with the following items:

Pencil

Test Booklet

Answer Sheets

BGE/L Service Manual

BGE/L Parts Manual

Print #611-1174

Three colored markers

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

When you are finished with the test, please place all test booklets, answer sheets, and colored markers on the table at the back of the room, and take a break.

When all test materials have been handed out and all instructions given, you will be told to START. Although there is no time limit for the test, please work as carefully and quickly as you can.

This test should take you approximately one and one-half hours.

DO NOT TURN THE PAGE UNTIL YOU ARE TOLD TO START

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

1. After you interview the generator set owner, using the systematic troubleshooting method, you would next

   A. decide on a possible bad part.
   B. decide on a possible problem system.
   C. verify the owner's problem.
   D. write down checks needed to find the bad part.

2. A valve stem seal is found most often on

   A. intake valves.
   B. oil pressure relief valves.
   C. crankcase breather valves.
   D. exhaust valves.

3. Reversing the current flow through a coil

   A. reduces the amount of flux produced.
   B. reverses its two-pole field.
   C. reduces the amount of power consumed.
   D. reduces eddy currents.

4. Using a leak down tester, you observe 40% leakage and a whistling noise at the dipstick tube. What problem have you isolated?

   A. Bad valve seating.
   B. Bad rings.
   C. Worn intake guides.
   D. Crankcase vacuum problem

5. Magnetism created by a flow of electric current is

   A. indicated magnetism.
   B. electromagnetism.
   C. mutual magnetism.
   D. potential magnetism.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

6. If you were taking voltage measurements along a circuit to find a problem, you would be using the_____ troubleshooting method.

   A. Systematic
   B. Big Three
   C. Quick Checks
   D. Easy-Likely

7. Amperage is

   A. the opposition to current flow through a conductor.
   B. the pressure pushing the current through a conductor.
   C. the rate at which current flows through a conductor.
   D. measured in terms of ohms.

8. When the sides of the armature coil move at right angles to the magnetic flux

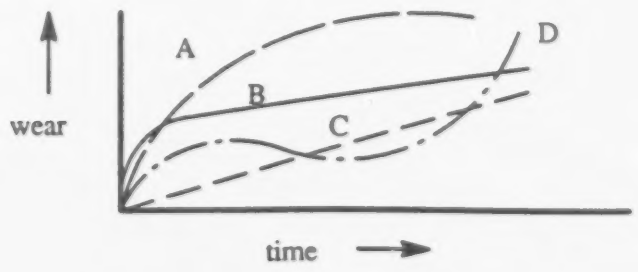
   A. the highest voltage is produced.
   B. medium voltage is produced.
   C. low voltage is produced.
   D. zero voltage is produced.

9. An example of a failure in the fuel system which fits into the Easy-Likely block would be a

   A. plugged pickup tube in the fuel tank.
   B. loose inlet fitting at the carburetor.
   C. stuck choke pull-off rod.
   D. misadjusted carburetor float.

10. On the graph below, which line best indicates how an engine wears over time?

   A. Line A.
   B. Line B.
   C. Line C.
   D. Line D.



Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

11. Resistance is

A. the opposition to current flow through a conductor.
B. the pressure pushing the current through a conductor.
C. the rate at which current flows through a conductor.
D. measured in terms of voltage.

12. The output frequency of an AC generator is dependent upon the

A. number of poles and phases.
B. rotor speed and phases.
C. number of poles and the type of prime mover.
D. number of poles and the rotor speed.

13. A fundamental law of electricity is that the current in a circuit is

A. inversely proportional to the voltage.
B. equal to the voltage.
C. directly proportional to the resistance.
D. directly proportional to the voltage.

14. According to Ohm's Law

A. to find the amperage, multiply the voltage by the resistance.
B. to find the voltage, divide the amperage by the resistance.
C. to find the resistance, multiply the voltage by the amperage.
D. none of the above are correct.

15. To determine which system the problem is in when the generator set starts and runs but will not stop would be the _____ method.

A. Quick Checks
B. Half-Half
C. Easy-Likely
D. Big Three

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

16. Which of the following is a poisonous gas given off from a running gasoline engine?

A. Carbon dioxide.
B. Carbon monoxide.
C. Nitrogen.
D. Oxygen.

17. Which of the following occurs when a conductor moves across a magnetic field?

A. Voltage is induced in the conductor.
B. The magnetic field strength increases.
C. The magnetic field strength decreases.
D. Voltage is reduced in the conductor.

18. What state must the air-fuel mixture be in for good combustion?

A. Liquid
B. Vapoprized
C. Solid
D. None of the above

19. In a parallel circuit containing a 4-ohm, 5-ohm, and 6-ohm resistor, the current flow is

A. highest through the 4-ohm resistor.
B. lowest through the 4-ohm resistor.
C .highest through the 6-ohm resistor.
D. the same for all (equal through all resistors).

20. Induced voltage can be increased by

A. increasing the magnetic field strength.
B .increasing the speed of the lines of force cutting across a conductor.
C. increasing the number of conductors cutting through the lines of force.
D. all of the above.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

21. The process by which current in one conductor creates a voltage in another is

A induction.

B. capacitance.

C conductance.

D. lamination.

22. An engine with approximately 100 hours use is using abnormal amounts of oil. It is not leaking oil. A partial teardown reveals that the cylinder bore is glazed. What is the most probable cause?

A. Use of poor quality fuel.

B. Incorrect weight of oil.

C. Excessive loading during break-in.

D. Insufficient load during break-in.

23. The unit of Electro Motive Force (EMF) is the

A. ampere.

B. volt.

C. ohm.

D. watt.

24. Which component in Onan 2-cylinder engine governors is most responsible for increasing throttle position when a load is applied?

A. The flyballs and governor cup.

B. The governor spring.

C. The sensitivity clip.

D. The speed adjust nut.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

25. The voltage output of an AC generator is usually controlled by

A. varying the number of windings in the stator.
B. varying the DC exciter voltage.
C. varying the reluctance of the air gap.
D. shorting out part of the armature windings.

26. What type of electrical circuit contains all of it's components "in line"?

A. Series
B. Parallel
C. Series-parallel
D. Electro-mechanical

Instructions: Use Onan Print # 611-1174 for Questions 27through 36.

27. What do components K3, K4, R1, K2 have in common?

A. All are part of the start system.
B. All are part of the stop system.
C. All are mounted on the A1 board.
D. All are D.C. components.

28. To obtain maximum no-load A.C. output voltage connect leads S1 and CR4 - AC to connections

A. X1, K6
B. X3, X6
C. X1, X4
D. X3, X4

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

29. Component S2's function is

A. to close on oil pressure.
B. to open on oil pressure.
C. to lock-out start ignition until oil pressure rises.
D. A & C.

30. When the start switch is pressed the set fails to crank. A voltage check indicates 12 volts at terminal S1 on relay K1 with the start switch pressed. What component would you check next?

A. S2
B. K2
C. K4
D. B1

31. How many volts would you expect to find at A1-P3-6 with the unit running?

A. 0 volts
B. 6 - 7 volts
C. 13 - 14 volts
D. 120 volts

32. When the set is being cranked but has not yet started, B+ to the ignition coil is supplied thru the closed set of

A. A1 - K4 contacts.
B. A1 - K3 contacts.
C. K5 contacts.
D. K1 contacts.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

33. Which stator winding provides battery charging, choke pull off, and run signal to the control?

A. T1 - T2
B. T3 - T4
C. S1 - S2
D. B1 - B2

34. Component A1-K2 and A1-K3 could be described as

A. run relays.
B. crank relays.
C. stop relays.
D. start relays.

35. With fuse A1 - F1 removed the set will

A. start but not run.
B. crank but not start.
C. run but not stop.
D. do absolutely nothing.

36. How many volts would you expect to find at A1-P3-6with the unit cranking?

A. 0 volts
B. 4 - 6 volts
C. 10 - 12 volts
D. 120 volts

Instructions: Answer the following calculation questions to the best of your ability. Please place the formula you used and your answer in the spaces provided on the answer sheet.

37. What is the output of a GenSet which has a load of54 amps at 120 volts, with unity power factor?

38. Lamps having a resistance of 10 ohms, 40 ohms, and60 ohms respectively are connected in series. What is the total resistance of the circuit?

39. A resistor of 5 ohms is connected in parallel with a resistor of 20 ohms. What is the equivalent resistance of these resistors?

40. How much current is needed to operate a soldering iron which has a rating of 600 watts at 100 volts?

41. Four lamps, each drawing 1/2 ampere, are connected in parallel across a 110-volt generator. What is the current flowing in the entire circuit?

Instructions: Using the Onan Service Manual for the BGE-BGEL GenSets, find the following information and list the page where it is located.

42 ._____ On what page can you find the causes of low oil pressure in the engine?

43. _____ On what page can you find the procedures for testing the CR4 bridge rectifier?

44. _____ On what page can you find the causes for the engine cranking but not starting?

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

Instructions: Using Parts Manual for the BGE-BGEL GenSet, find the part number for each of the following items.

45. _____ BGE Control Wiring Harness (with 8-pin connector)

46. _____ Transformer-Regulator

47. _____ Piston Ring Set (.020" oversize)

Instructions for questions 48 through 50:

Using the schematic drawing for the BGE GenSet on the second answer sheet, determine which circuits are energized while the GenSet is RUNNING.

Trace the energized circuits using the following colors:

48.Red Circuits with B+ current

49.Green Circuits with B- ground

50.Blue Circuits with AC current

EMERALD GENERATOR SET PRE-TEST ANSWER SHEET

NAME: _____DATE: _____

For Questions 1 through 26, choose the most correct answer and blacken the corresponding answer on the answer sheet.

Example: E1. An elephant is a

A. mammal.
B. vegetable.
C. mineral.
D. tree.

E1. ● B C D

1.	A B C D	14.	A B C D
2.	A B C D	15.	A B C D
3.	A B C D	16.	A B C D
4.	A B C D	17.	A B C D
5.	A B C D	18.	A B C D
6.	A B C D	19.	A B C D
7.	A B C D	20.	A B C D
8.	A B C D	21.	A B C D
9.	A B C D	22.	A B C D
10.	A B C D	23.	A B C D
11.	A B C D	24.	A B C D
12.	A B C D	25.	A B C D
13.	A B C D	26.	A B C D

For questions 27 through 36, refer to Onan print #611-1174; select the most correct answer and blacken the corresponding answer on the answer sheet.

27.	A B C D	32.	A B C D
28.	A B C D	33.	A B C D
29.	A B C D	34.	A B C D
30.	A B C D	35.	A B C D
31.	A B C D	36.	A B C D

For questions 37 through 41, perform the required calculations and place your answer and the formula used in the proper spaces.

37. Your Answer _____ Formula used _____
38. Your Answer _____ Formula used _____
39. Your Answer _____ Formula used _____
40. Your Answer _____ Formula used _____
41. Your Answer _____ Formula used _____

For questions 42 through 44 refer to the Emerald Service Manual. Find the correct page, and mark its number in the corresponding space.

42._____ Page Number
43._____ Page Number
44._____ Page Number

For questions 45 through 47 refer to the Emerald Parts Manual. Find the correct part number, and mark it in the corresponding space.

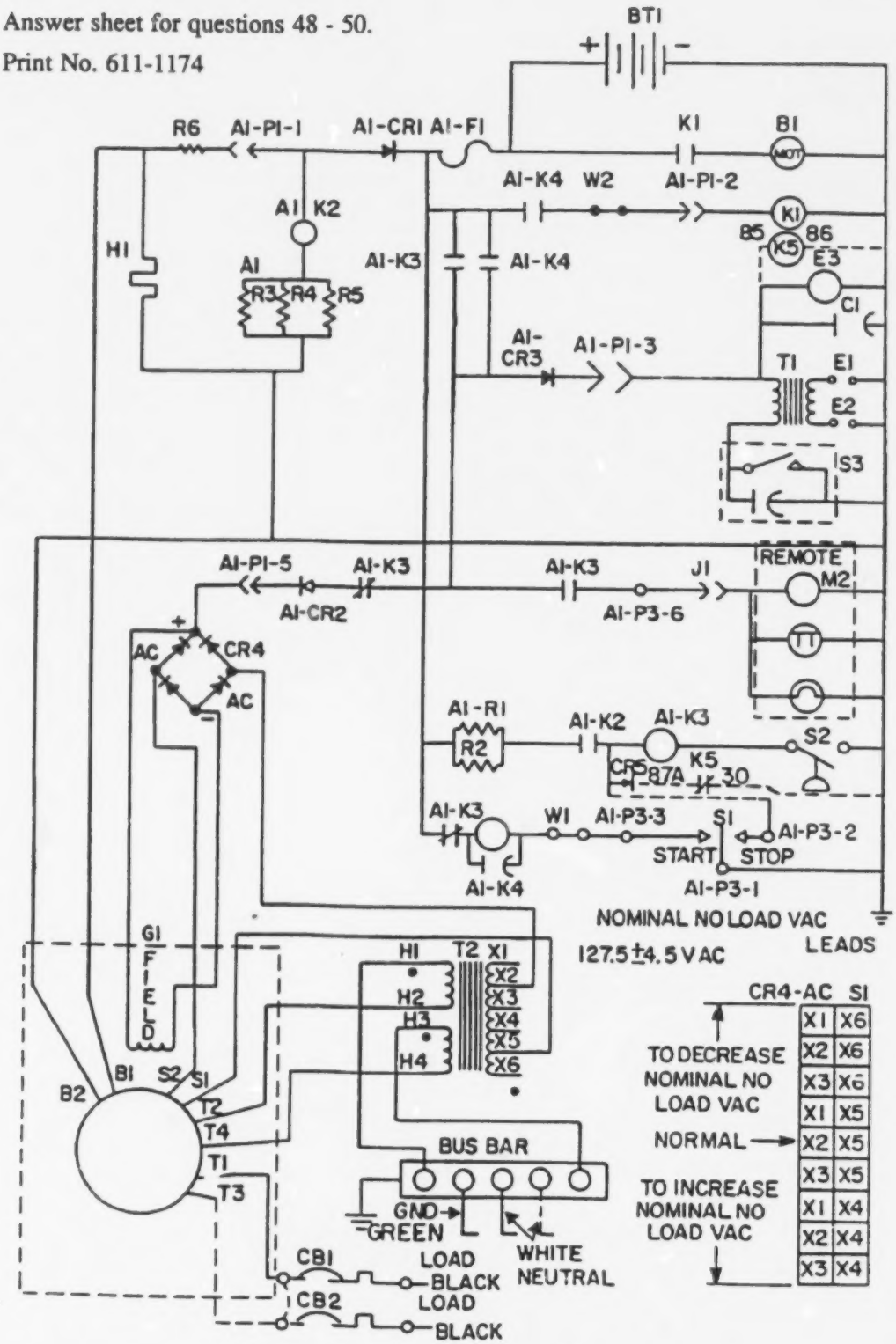
45._____ Part Number
46._____ Part Number
47._____ Part Number

For questions 48 through 50, trace the appropriate circuits on the 611-1174 print answer sheet using the colored pencils provided.

48. B+ circuits in RED
49. Ground (B-) circuits in GREEN
50. AC circuits in BLUE

Answer sheet for questions 48 - 50.

Print No. 611-1174



APPENDIX E

DECLARATIVE KNOWLEDGE POST-TEST AND ANSWER SHEET

EMERALD GENERATOR SET POST-TEST

This test is designed to check your knowledge in the following eight areas:

1. Basic Magnetics area
2. Basic Electrical / Electronics area
3. Basic Mechanical area
4. The 4.0 BGE Emerald Control (Print #611-1174)
5. Ohm's Law
6. Using the BGE/L Service Manual
7. Using the BGE/L Parts Manual
8. Troubleshooting Methods

You will be provided with the following items:

Pencil

Test Booklet

Answer Sheets

BGE/L Service Manual

BGE/L Parts Manual

Print #611-1174

Three colored markers

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

When you are finished with the test, please place all test booklets, answer sheets, and colored markers on the table at the back of the room, and take a break.

When all test materials have been handed out and all instructions given, you will be told to START. Although there is no time limit for the test, please work as carefully and quickly as you can.

This test should take you approximately one hour.

DO NOT TURN THE PAGE UNTIL YOU ARE TOLD TO START

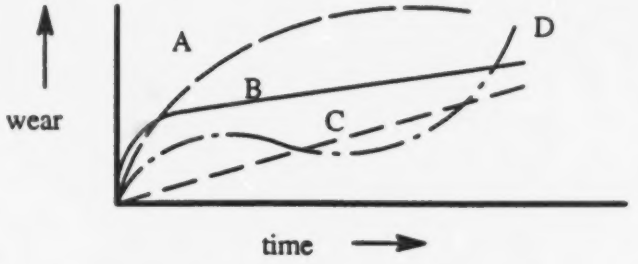
Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

1. Magnetism created by a flow of electric current is

   A. indicated magnetism.
   B. electromagnetism.
   C. mutual magnetism.
   D. potential magnetism.

2. On the graph below, which line best indicates how an engine wears over time?

   A. Line A.
   B. Line B.
   C. Line C.
   D. Line D.



3. The output frequency of an AC generator is dependent upon the

   A. number of poles and phases.
   B. rotor speed and phases.
   C. number of poles and the type of prime mover.
   D. number of poles and the rotor speed.

4. After you interview the generator set owner, using the systematic troubleshooting method, you would next

   A. decide on a possible bad part.
   B. decide on a possible problem system.
   C. verify the owner's problem.
   D. write down checks needed to find the bad part.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

5. Which component in Onan 2-cylinder engine governors is most responsible for increasing throttle position when a load is applied?

   A. The flyballs and governor cup.
   B. The governor spring.
   C. The sensitivity clip.
   D. The speed adjust nut.

6. When the sides of the armature coil move at right angles to the magnetic flux

   A .the highest voltage is produced.
   B. medium voltage is produced.
   C. low voltage is produced.
   D. zero voltage is produced.

7. An example of a failure in the fuel system which fits into the Easy-Likely block would be a

   A. plugged pickup tube in the fuel tank.
   B. loose inlet fitting at the carburetor.
   C. stuck choke pull-off rod.
   D. misadjusted carburetor float.

8. Resistance is

   A. the opposition to current flow through a conductor.
   B. the pressure pushing the current through a conductor.
   C. the rate at which current flows through a conductor.
   D. measured in terms of voltage.

9. A valve stem seal is found most often on

   A. intake valves.
   B. oil pressure relief valves.
   C. crankcase breather valves.
   D. exhaust valves.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

10. Induced voltage can be increased by

    A. increasing the magnetic field strength.
    B. increasing the speed of the lines of force cutting across a conductor.
    C. increasing the number of conductors cutting through the lines of force.
    D. all of the above.

11. What type of electrical circuit contains all of it's components "in line"?

    A. Series
    B. Parallel
    C. Series-parallel
    D. Electro-mechanical

12. Amperage is

    A. the opposition to current flow through a conductor.
    B. the pressure pushing the current through a conductor.
    C. the rate at which current flows through a conductor.
    D. measured in terms of ohms.

13. A fundamental law of electricity is that the current in a circuit is

    A. inversely proportional to the voltage.
    B. equal to the voltage.
    C. directly proportional to the resistance.
    D. directly proportional to the voltage.

14. The voltage output of an AC generator is usually controlled by

    A. varying the number of windings in the stator.
    B. varying the DC exciter voltage.
    C. varying the reluctance of the air gap.
    D. shorting out part of the armature windings.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

15. The unit of Electro Motive Force (EMF) is the

A. ampere.
B. volt.
C. ohm.
D. watt.

16. Using a leak down tester, you observe 40% leakage and a whistling noise at the dipstick tube. What problem have you isolated?

A. Bad valve seating.
B. Bad rings.
C. Worn intake guides.
D. Crankcase vacuum problem

17. In a parallel circuit containing a 4-ohm, 5-ohm, and6-ohm resistor, the current flow is

A. highest through the 4-ohm resistor.
B. lowest through the 4-ohm resistor.
C. highest through the 6-ohm resistor.
D. the same for all (equal through all resistors).

18. If you were taking voltage measurements along a circuit to find a problem, you would be using the_____ troubleshooting method.

A. Systematic
B. Big Three
C. Quick Checks
D. Easy-Likely

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

19. Which of the following occurs when a conductor moves across a magnetic field?

A. Voltage is induced in the conductor.
B. The magnetic field strength increases.
C. The magnetic field strength decreases.
D. Voltage is reduced in the conductor.

20. The process by which current in one conductor creates a voltage in another is

A. induction.
B. capacitance.
C. conductance.
D. lamination.

21. According to Ohm's Law

A. to find the amperage, multiply the voltage by the resistance.
B. to find the voltage, divide the amperage by the resistance.
C. to find the resistance, multiply the voltage by the amperage.
D. none of the above are correct.

22. An engine with approximately 100 hours use is using abnormal amounts of oil. It is not leaking oil. A partial teardown reveals that the cylinder bore is glazed. What is the most probable cause?

A. Use of poor quality fuel.
B. Incorrect weight of oil.
C. Excessive loading during break-in.
D. Insufficient load during break-in.

23. Reversing the current flow through a coil

A. reduces the amount of flux produced.
B. reverses its two-pole field.
C. reduces the amount of power consumed.
D. reduces eddy currents.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

24. To determine which system the problem is in when the generator set starts and runs but will not stop would be the _____ method.

A. Quick Checks
B. Half-Half
C. Easy-Likely
D. Big Three

25. Which of the following is a poisonous gas given off from a running gasoline engine?

A. Carbon dioxide.
B. Carbon monoxide.
C. Nitrogen.
D. Oxygen.

26. What state must the air-fuel mixture be in for good combustion?

A. Liquid
B. Vaporized
C. Solid
D. None of the above

Instructions: Use Onan Print # 611-1174 for Questions 27 through 36.

27. What do components K3, K4, R1, K2 have in common?

A. All are part of the start system.
B. All are part of the stop system.
C. All are mounted on the A1 board.
D. All are D.C. components.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

28. Component A1-K2 and A1-K3 could be described as

A. run relays.
B. crank relays.
C. stop relays.
D. start relays.

29. When the set is being cranked but has not yet started, B+ to the ignition coil is supplied thru a closed set of

A. A1 - K4 contacts.
B. A1 - K3 contacts.
C. K5 contacts.
D. K1 contacts.

30. When the start switch is pressed the set fails to crank. A voltage check indicates 12 volts at terminal S1 on relay K1 with the start switch pressed. What component would you check next?

A .S2
B. K2
C. K4
D. B1

31. With fuse A1 - F1 removed the set will

A. start but not run.
B. crank but not start.
C. run but not stop.
D. do absolutely nothing.

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

32. To obtain maximum no-load A.C. output voltage connect leads S1 and CR4 - AC to connections

A. X1, K6
B. X3, X6
C. X1, X4
D. X3, X4

33. How many volts would you expect to find at A1-P3-6with the unit running?

A. 0 volts
B. 6 - 7 volts
C. 13 - 14 volts
D. 120 volts

34. Which stator winding provides battery charging,choke pull off, and run signal to the control?

A. T1 - T2
B. T3 - T4
C. S1 - S2
D. B1 - B2

35. How many volts would you expect to find at A1-P3-6with the unit cranking?

A. 0 volts
B. 4 - 6 volts
C. 10 - 12 volts
D. 120 volts

36. Component S2's function is

A. to close on oil pressure.
B. to open on oil pressure.
C. to lock-out start ignition until oil pressure rises.
D. A & C.

Instructions: Answer the following calculation questions to the best of your ability. Please place the formula you used and your answer in the spaces provided on the answer sheet.

37. Four lamps, each drawing 1/2 ampere, are connected in parallel across a 110-volt generator. What is the current flowing in the entire circuit?

38. What is the output of a GenSet which has a load of 54 amps at 120 volts, with unity power factor?

39. Lamps having a resistance of 10 ohms, 40 ohms, and 60 ohms respectively are connected in series. What is the total resistance of the circuit?

40. How much current is needed to operate a soldering iron which has a rating of 600 watts at 100 volts?

41. A resistor of 5 ohms is connected in parallel with a resistor of 20 ohms. What is the equivalent resistance of these resistors?

Instructions: Using the Onan Service Manual for the BGE-BGEL GenSets, find the following information and list the page where it is located.

42. _____ On what page can you find the causes of low oil pressure in the engine?

43. _____ On what page can you find the procedures for testing the CR4 bridge rectifier?

44. _____ On what page can you find the causes for the engine cranking but not starting?

Please mark all of your answers, and formulas where used, in the spaces provided on the answer sheets.

Instructions: Using Parts Manual for the BGE-BGEL GenSet, find the part number for each of the following items.

45. _____ BGE Control Wiring Harness (with 8-pin connector)

46. _____ Transformer-Regulator

47. _____ Piston Ring Set (.020" oversize)

Instructions for questions 48 through 50:

Using the schematic drawing for the BGE GenSet on the third answer sheet, determine which circuits are energized while the GenSet is RUNNING.

Trace the energized circuits using the following colors:

48.Red Circuits with B+ current

49.Green Circuits with B- ground

50.Blue Circuits with AC current

EMERALD GENERATOR SET POST-TEST ANSWER SHEET

NAME: _____DATE: _____

For Questions 1 through 26, choose the most correct answer and blacken the corresponding answer on the answer sheet.

Example: E1. An elephant is a

A. mammal.
B. vegetable.
C. mineral.
D. tree.

E1. ● B C D

1.	A B C D	14.	A B C D
2.	A B C D	15.	A B C D
3.	A B C D	16.	A B C D
4.	A B C D	17.	A B C D
5	.A B C D	18.	A B C D
6.	A B C D	19.	A B C D
7.	A B C D	20.	A B C D
8.	A B C D	21.	A B C D
9.	A B C D	22.	A B C D
10.	A B C D	23.	A B C D
11.	A B C D	24.	A B C D
12.	A B C D	25.	A B C D
13.	A B C D	26.	A B C D

For questions 27 through 36, refer to Onan print #611-1174; select the most correct answer and blacken the corresponding answer on the answer sheet.

27.	A B C D	32.	A B C D
28.	A B C D	33.	A B C D
29.	A B C D	34.	A B C D
30.	A B C D	35.	A B C D
31.	A B C D	36.	A B C D

For questions 37 through 41, perform the required calculations and place your answer and the formula used in the proper spaces.

37. Your Answer _____ Formula used _____
38. Your Answer _____ Formula used _____
39. Your Answer _____ Formula used _____
40. Your Answer _____ Formula used _____
41. Your Answer _____ Formula used _____

For questions 42 through 44 refer to the Emerald Service Manual. Find the correct page, and mark its number in the corresponding space.

42._____ _____ Page Number
43._____ Page Number
44._____ Page Number

For questions 45 through 47 refer to the Emerald Parts Manual. Find the correct part number, and mark it in the corresponding space.

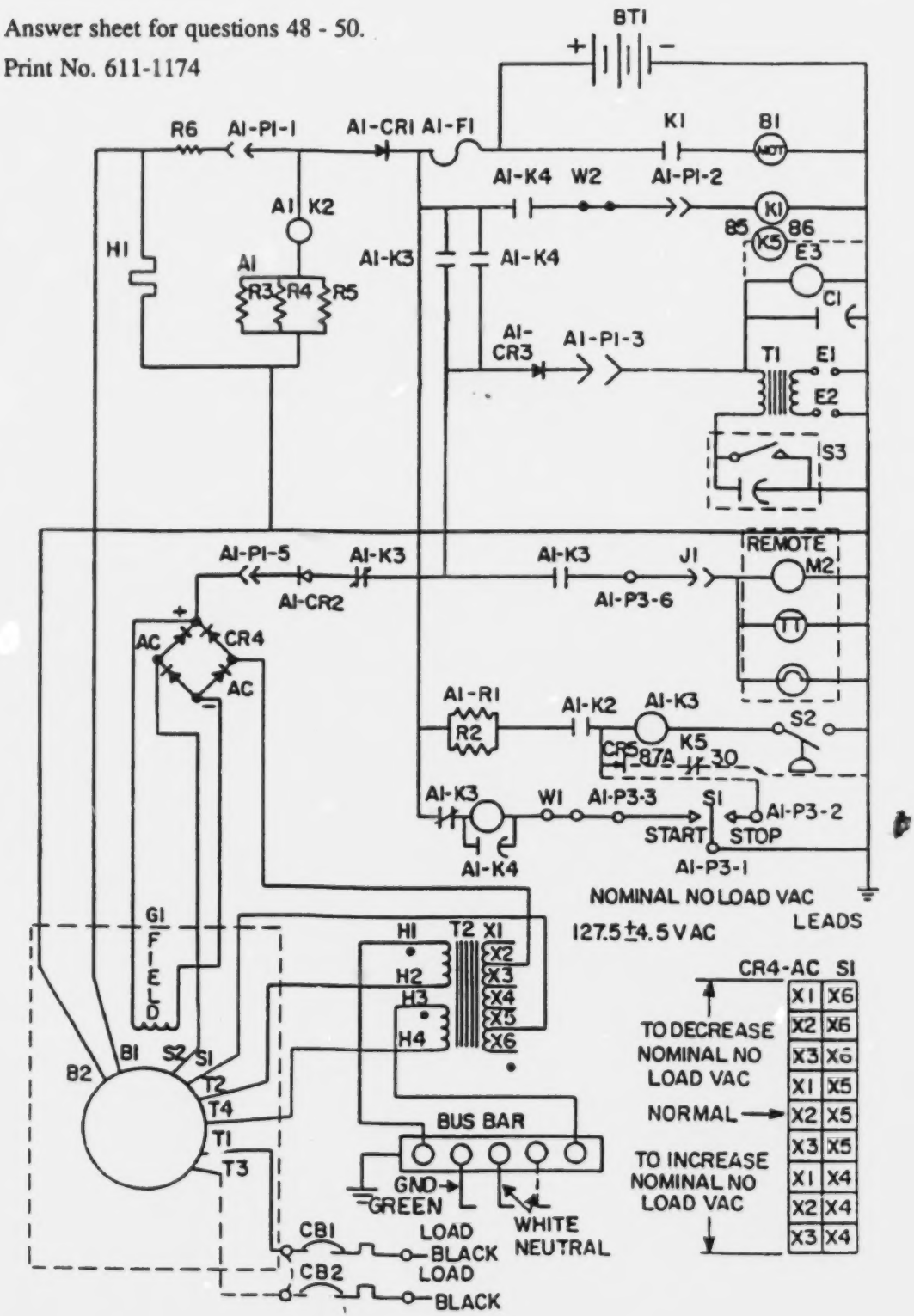
45._____ Part Number
46._____ Part Number
47._____ Part Number

For questions 48 through 50, trace the appropriate circuits on the 611-1174 print answer sheet using the colored pencils provided.

48. B+ circuits in RED
49. Ground (B-) circuits in GREEN
50. AC circuits in BLUE

Answer sheet for questions 48 - 50.

Print No. 611-1174



APPENDIX F

CONTROL GROUP TREATMENT OUTLINE

Table 21.

Control group treatment outline.

Monday		
	8:00	Ground Rules, Introductions
	9:00	Pre-Test
	10:00	Go over Pre-Test
	11:30	Lunch
	12:00	Model/Spec and Safety
	1:30	Emerald Disassembly
Tuesday		
	8:00	Basic Electricity
	11:30	Lunch
	12:00	Generator Theory and Operation
Wednesday		
	8:00	Emerald reassembly
	11:30	Lunch
	12:00	Test and Adjust
	1:30	Procedural Performance Examination
Thursday		
	8:00	Disassemble BFA & NH Generator / Control
	10:30	BFA/NH Control Theory of Operation
	11:30	Lunch
	12:00	Reassemble BFA & NH Generator Sets
	2:00	Test and Adjust
	3:00	Troubleshooting of BFA/NH Generator Sets
Friday		
	8:00	Warranty / Liability
	9:30	Parts
	10:00	Post-Test, Review & Scoring of Tests
	11:30	Leave for Graduation Lunch
	1:00	Factory Tour

APPENDIX G

EXPERIMENTAL GROUP TREATMENT OUTLINE AND TROUBLESHOOTING METHOD INFORMATION SHEETS

Table 22.

Experimental group treatment outline.

Monday		
	8:00	Ground Rules, Introductions
	9:00	Pre-Test
	10:00	Go over Pre-Test
	11:30	Lunch
	12:00	Troubleshooting Methods Lesson
	1:00	Model/Spec and Safety
	2:00	Emerald Disassembly
Tuesday		
	8:00	Basic Electricity
	11:30	Lunch
	12:00	Generator Theory and Operation
Wednesday		
	8:00	Emerald reassembly
	11:30	Lunch
	12:00	Test and Adjust
	1:30	Procedural Performance Examination
Thursday		
	8:00	Disassemble BFA & NH Generator / Control
	10:30	BFA/NH Control Theory of Operation
	11:30	Lunch
	12:00	Reassemble BFA & NH Generator Sets
	2:00	Test and Adjust
	3:00	Troubleshooting of BFA/NH Generator Sets
Friday		
	8:00	Warranty / Liability
	9:30	Parts
	10:00	Post-Test, Review & Scoring of Tests
	11:30	Leave for Graduation Lunch
	1:00	Factory Tour

Table 23.

Troubleshooting methods discussed in the troubleshooting methods lesson of the experimental treatment.

METHOD NAME	IDENTIFICATION POINTS
1: QUICK CHECKS	The most common failures for that equipment, system, or sub-system of the equipment.
2: BIG-3	Decide on which of three possible options is the most probable as the cause of the present problem.
3: EASY-LIKELY	Dividing the possible causes to be checked into a four-part matrix, and checking the most likely and easiest to check first.
4: HALF-HALF	Dividing the most possible system or sub-system in half and checking at that point for proper indication. This process is continued until the problem cause has been identified.
5: SEQUENTIAL	A systematic method of troubleshooting which flows from interviewing the customer through Quick Checks, The BIG-3, Easy-Likely, and Troubleshooting aids in the Service Manual to a positive solution which results in a satisfied customer quickly back on his/her way to a vacation destination.

Troubleshooting Methods Explanation

Quick Checks are solutions to problems on a particular engine, generator set, or electrical device that happen with regularity. These checks are used by expert troubleshooters because they provide reliable, time-tested solutions to equipment failures. The number of quick checks for any specific unit is usually kept to a maximum of five. For example, the first quick check for the Emerald generator set is to check the oil level in the crankcase. The condition and level of oil tells the service person several things about the generator set:(1) If the owner takes care of the generator set and changes the oil regularly,

(2) What kind of operating conditions the generator set has been used in (from the color, feel, and smell of the oil), and (3) Is there gasoline in the oil. If there is no oil, or a low level of oil, that may be the solution to a "generator set doesn't run" problem, because the generator set must have oil pressure to run. If the oil has a burned smell, the generator set may have been overheating, and the service person will look for plugged cooling fins, etc. If there is gasoline in the oil, the most prevalent cause is a failed mechanical fuel pump. The other quick checks are similar specific checks that can pinpoint the system which is most likely to cause the fault.

The second method of troubleshooting explained in the Experimental course curriculum was the **Easy-likely** method. In this method, the troubleshooter tries likely repairs that are easy to perform (Easy-Likely) first, and progressively moves toward unlikely repairs that are difficult to perform (Difficult-Unlikely) to find problems uncovered using the Quick Checks troubleshooting method. These checks are random in nature and naturally jump through the generator set's systems, and from system to system as the service person checks all the possible solutions to a particular problem in the Easy-Likely to Difficult-Unlikely grid format as shown in Figure 7.

	Likely to fail items	Unlikely to fail items
Easily checked items	Easy-Likely	Easy-Unlikely
Hard to check items	Difficult-Likely	Difficult-Unlikely

Figure 7. Easy-likely method grid format.

Easy-Likely: Easy to check possible solution which is Likely to cause the problem.

Easy-Unlikely: Easy to check possible solution which is Unlikely to cause the problem.

Difficult-Likely: Difficult to check possible solution which is Likely to cause the problem.

Difficult-Unlikely: Difficult to check solution which is Unlikely to cause the problem.

Normally, the troubleshooting chart(s) in the Onan Recreational Vehicle (RV) generator set Service Manuals are arranged in an Easy-Likely to Difficult-Unlikely sequence.

The third method explained to the experimental class in this lesson was The **Big Three**. This the most-used troubleshooting method in the Onan factory schools. This troubleshooting method was explained to the students as a troubleshooting method which can be used in almost any situation to move from a large problem to a specific assembly or subassembly. With this method, shown in Figure 8, the troubleshooter can determine whether the problem is an engine problem (fuel, air, ignition), a generator problem (voltage build-up, transformer output, regulator bridge), or a control circuit problem (start, run, stop). This troubleshooting method is divided into levels, and the troubleshooter moves from the generator set level to a major component level, to a system level, to a minor system level, to a series of components which can be checked for proper operation.

LEVEL #1: GENERATOR SET ENGINE - CONTROL - GENERATOR

Figure 8. Big Three troubleshooting method, level 1.

Level #1 is divided into the three major systems, and each of these systems is further subdivided in level #2 as shown in Figure 9.

LEVEL #2: ENGINE:	FUEL -	AIR	- IGNITION
LEVEL #2: CONTROL:	START -	RUN	- STOP
LEVEL #2 GENERATOR:	BUILD-UP-TRANSFORMER-BRIDGE		

Figure 9. Engine, Control, and Generator, level 2 subdivisions of the Big-Three troubleshooting method.

As shown in Figure 10, each of the major systems is further divided into its three main components or functions. The engine is subdivided into the fuel, air, and ignition systems since these are required to sustain combustion. If combustion stops, the engine stops. The control is subdivided into the start, run, and stop circuits. This is because the control operates in three distinct modes, and different components are used in these three modes. The generator is subdivided into the voltage build-up (field-flash) circuits, output (load connection) circuits, and the exciter bridge (voltage regulation) circuits. Each of these subdivisions can be further divided into sub-systems or components which can be checked for faults which are causing the present failure. For this example, let us presume that the problem is in the engine which is further divided into the three systems which are required to sustain combustion: Fuel, Air, and Ignition. A fuel problem could be anything from a dry fuel tank to a plugged fuel passage in the carburetor; an air problem could be anywhere in the air cleaner to intake valve path; and an ignition problem could be anywhere from the battery ground connection to the spark plug electrode. The troubleshooter would first determine what was not available to sustain combustion, and then investigate that system. This investigation could be either in a sequential (start to end) fashion, or in a divide and check fashion (which is covered in the Half-Half troubleshooting method).

The fourth troubleshooting method explained to the experimental class was the **Half-half** method. This is the most useful method in finding solutions to electrical problems. In this method the troubleshooter determines where the "middle" of the faulty circuit can be easily checked by use of a schematic diagram. If tests at that point show the proper indication, the problem is between the point tested and the output of the circuit. If tests do not show the proper indication, the problem is between the tested point and the input to the circuit, as shown in Figure 10. The troubleshooter determines which direction to move in the circuit, and the next test point and proper indication for that point. The troubleshooter continues with this method of dividing the circuit in half until the problem is found.

An improper indication at "A" means the problem is in this half of the diagram.

A proper indication at "A" means the problem is in this half of the diagram.

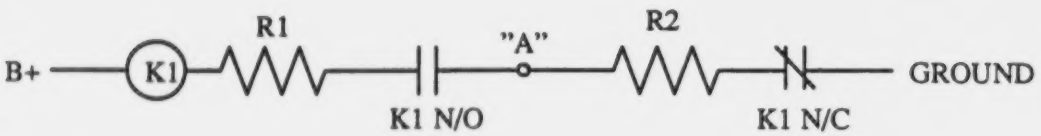


Figure 10. Half-Half troubleshooting method diagram.

The fifth of the troubleshooting methods introduced to the experimental class was **Systematic Troubleshooting.** This method includes parts of all of the above methods in a sequential matrix. Some troubleshooters use a method or plan like this, and others develop their own "style" of troubleshooting which is based on a similar plan. All effective troubleshooters have a tested plan used in troubleshooting all failures. The systematic troubleshooting method, which is a General-Purpose troubleshooting plan is displayed in Figure 11.

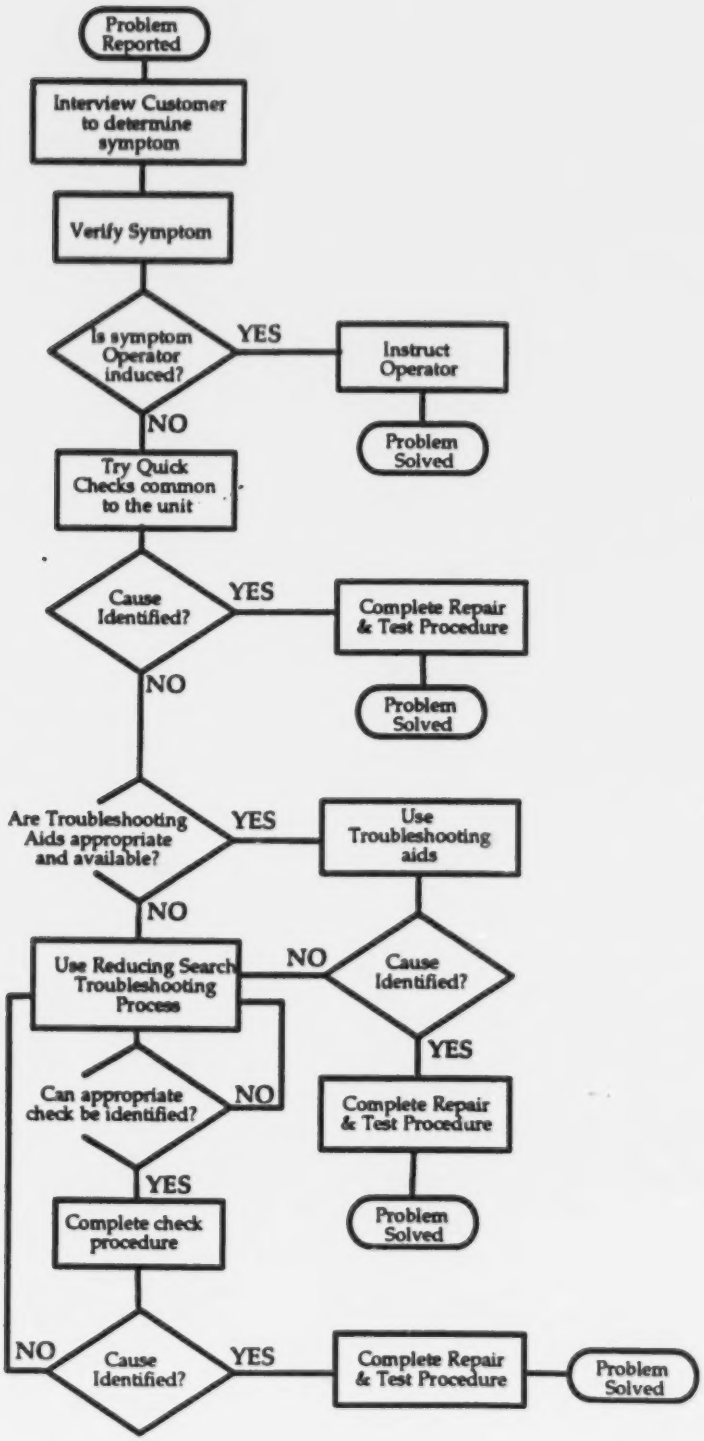


Figure 11. Sequential troubleshooting method flow chart.

APPENDIX H

PROCEDURAL PERFORMANCE TEST INSTRUCTIONS

Instructions given to all Subjects as they entered the Procedural Performance Test Area:

A customer left this Emerald generator set in the shop yesterday with the following discrepancy:

"The generator set does not run."

We did not get a chance to ask the customer if that means:

Does the generator set crank?

If it cranks does it start,?

If it starts, when the customer removes his finger from the START switch, does the engine die?

Or is it just that there is no AC output?

We knew that (insert SS First Name) was coming in today. You are an expert troubleshooter, and would be able to easily find and repair the problem.

All the tools, test equipment, manuals, and prints that you will need are here on the work-bench. All that I would like you to do for me is tell me what you are doing, and what results you find in any checks you make so that we can teach trainees how an expert troubleshooter does the job correctly.

APPENDIX I

CONTROL GROUP TROUBLESHOOTING PROTOCOLS

Troubleshooting Protocol: Control Group Subject #1.

1. Tested voltage from battery to solenoid.
2. Checked switch to see if there is current flow to the solenoid.
3. Checked ground to switch - OK.
4. Checked from A1P1 pins 7 & 8 to B+ on K1 relay - 12 volts.
5. Checked A1J1 pins 7 & 8 to B+ - 12 volts.
6. Checked troubleshooting chart in Service manual.
7. Checked condition of LOPKO wire - OK.
8. Checked voltage on S1 pins - Ground.
9. Inspected A1J1 for visible damage.
10. Decided K1 was bad.

K1 bad - Wrong answer. - 24 minutes.

Troubleshooting Protocol: Control Group Subject # 2

1. Visual check of equipment.
2. Checked fuse F1 - OK.
3. Pressed START switch - no cranking, just fuel pump noise.
4. Checked troubleshooting chart in Service manual.
5. Checked battery voltage.
6. Checked A1P1 pin 6 to ground - OK.
7. Visually checked starter connection.
8. Checked voltage out of K1 relay with switch depressed - 0 volts.
9. Checked voltage to input of K1 relay - OK.
10. Checked continuity of P1 pin 2 to K1 pin s - infinite resistance.

Wire connection from A1 board pin 2 to P1 pin 2 bad - Correct answer - **14 minutes.**

Troubleshooting Protocol: Control Group Subject # 3

1 Pressed START switch - no cranking, fuel pump OK.

2. Pressed START switch - no cranking, fuel pump OK.

3. Checked battery voltage - OK.

4. Checked voltage at fuel pump connector with switch depressed - OK.

5. Checked voltage out of K1 with switch depressed - 0 volts.

6. Checked continuity form A1P1 pin 2 to K1 pin s - infinite resistance.

7. Visually checked P1 pin 2 - pin bad.

Pin 2 not making contact with circuit board - Correct answer - **6 minutes.**

Troubleshooting Protocol: Control Group Subject # 4

1. Pressed START switch - fuel pump clicks.

2. Checked battery voltage - OK.

3. Checked connection between battery cable and battery terminal - OK.

4. Checked continuity of fuse F1 - OK.

5. Checked continuity between A1J1 and P1 pins - meter lead not sharp enough to pierce coating on board.

6. Checked voltage at A1J6 - OK.

7. Checked A1J6 to A1J7 and A1J8 - OK.

8. Checked output voltage of K1 - 0 volts.

Board bad - Wrong answer - 8 minutes.

Troubleshooting Protocol: Control Group Subject # 5

1. Pressed START switch - fuel pump clicks.
2. Visually checked fuse F1.
3. Visual inspection of generator set and battery cables.
4. Checked battery voltage - OK.
5. Placed load output breaker in OFF position.
6. Visually inspected inside control panel area.
7. Checked troubleshooting chart in Service manual.
8. Checked output of K1 relay to ground with switch depressed - no voltage.

Wire from K1 relay to P1 pin 2 open - Wrong answer - 15 minutes.

Troubleshooting Protocol: Control Group Subject # 6

1. Pressed START switch - no cranking.
2. Checked ground cable - OK.
3. Checked battery voltage - OK.
4. Checked battery voltage with switch depressed - OK.
5. Checked K1 actuation terminal - 0 volts.
6. Checked A1J1 pin 2 to ground - OK.
7. Checked continuity from A1J1 pin 2 to P1 pin 2 - infinity.
8. Visualiy checked - P1 pin 2 broken.

P1 pin 2 bad - Correct answer - 13 minutes.

Troubleshooting Protocol: Control Group Subject # 7

1. Visually checked fuse F1.
2. Press START switch - no cranking.
3. Checked battery voltage - OK.
4. Visual check of generator set.
5. Checked input to K1 from battery - OK.
6. Visually checked inside control area.
7. Checked switch connections to ground 0 ohms
8. Checked input to K1 from battery - OK.
9. Checked output of K1 with switch depressed - 0 volts.
10. Pressed switch - fuel pump pumps.
11. Pressed switch - fuel pump pumps.
12. Pressed switch - fuel pump pumps.
13. Checked voltage at fuse F1 - OK.
14. Removed P1 - visually checked pins - re-installed P1.
15. Checked voltage from P1 pins 7 and 8 to A1J1 pin 6 - OK.
16. Checked A1J1 pin 2 with switch depressed - OK.
17. Checked voltage at K1 pin s - 0 volts.
18. P1 pin 2 bad.

P1 pin 2 bad - Correct answer - 20 minutes.

Troubleshooting Protocol: Control Group Subject # 8

1. Pressed START switch - fuel pump clicks, no cranking.
2. Checked battery voltage to K1 - OK.
3. Removed P1 for visual inspection.
4. P1 pin 2 loose and floppy, re-installed P1.
5. Checked continuity between A1J1 pin 2 and K1 pin s - infinity.
6. Check continuity from P1 pin 2 to A1J1 pin 2 - infinity.

P1 pin 2 bad - Correct answer - **5 minutes.**

Troubleshooting Protocol: Control Group Subject # 9

1. Pressed START switch - verified complaint - no cranking.
2. Checked battery voltage - OK.
3. Checked voltage at starter motor with switch depressed - 0 volts.
4. Visually checked inside control area.
5. Checked voltage at input of K1 - OK.
6. Checked voltage at K1 pin s with switch depressed - 0 volts.
7. Tried tracing wire in harness from K1 pin s to other end - got lost.
8. Checked schematic diagram for other end of wire from K1 pin s.
9. Checked voltage at P1 pin 6 - OK.
10. Checked voltage at P1 pin 2 with switch depressed - 0 volts.

P1 pin 2 bad - Correct answer - **14 minutes.**

Troubleshooting Protocol: Control Group Subject # 10

1. Pressed START switch - no cranking, sounds like chattering solenoid.
2. Checked battery voltage - OK.
3. Checked connections at starter solenoid - OK.
4. Checked voltage to K1 - OK.
5. Checked voltage at K1 with switch depressed - OK.
6. Checked voltage at K1 pin s1 - 0 volts; no voltage through starter solenoid.
7. Checked pin 3 at switch - OK.
8. Checked continuity between A1J1 and P1 pins; 1,3-8 OK, 2 bad.
9. Visually checked plug P1 for failure.

P1 pin 2 bad - Correct answer - **11 minutes.**

Troubleshooting Protocol: Control Group Subject # 11

1. Checked continuity of fuse F1 - OK.
2. Checked voltage at input to K1 - OK.
3. Checked voltage at P1 pin 6 - OK.
4. Checked voltage at P1 pin 2 with switch depressed - 0 volts.
5. Disconnected battery, checked continuity of switch with switch depressed - OK.
6. Reconnected battery, checked voltage at K1 pin s with switch depressed - 0 volts.
7. Checked continuity from K1 pin s to A1J1 pin 2 - infinity.

P1 pin 2 bad - Correct answer - **13 minutes.**

Troubleshooting Protocol: Control Group Subject # 12

1. Checked continuity of fuse F1 - OK.
2. Pressed START switch - fuel pump clicks.
3. Checked voltage at ignition coil with switch depressed - OK.
4. Checked battery voltage - OK.
5. Placed AC output circuit breaker in ON position.
6. Checked voltage at starter motor with switch depressed - 0 volts.
7. Checked continuity from A1J1 to P1 pins - 1,3-8 OK, 2 open.
8. Visually checked P1 pin 2 - pin 2 doesn't protrude as far down as the rest of the pins.

P1 pin 2 open - Correct answer - **11 minutes.**

APPENDIX J

CONTROL GROUP PROBLEM BEHAVIOR MAPS WITH THE PROBLEM SPACE HIGHLIGHTED

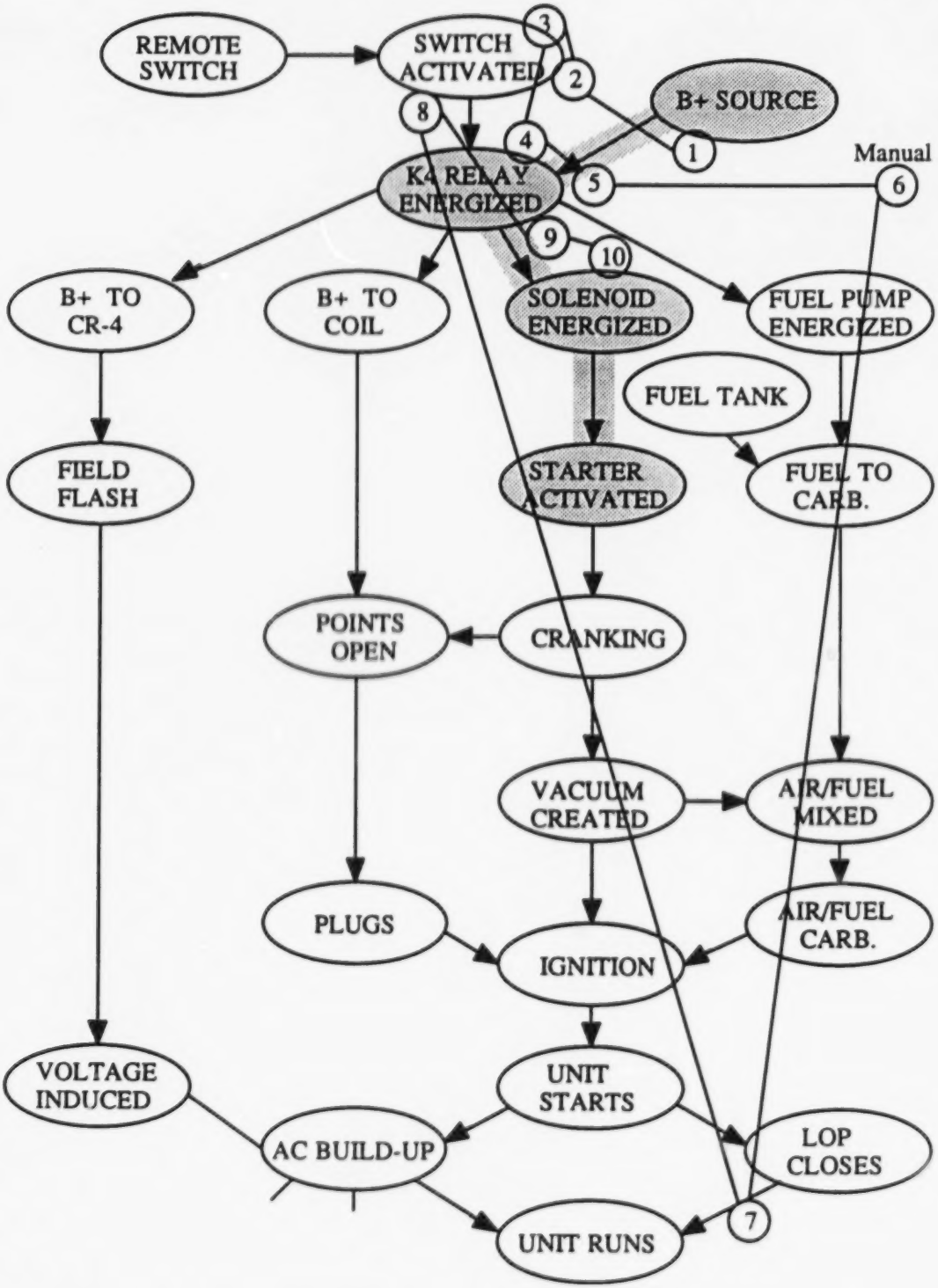


Figure 12. Control Group ss# 1 Problem Behavior Map

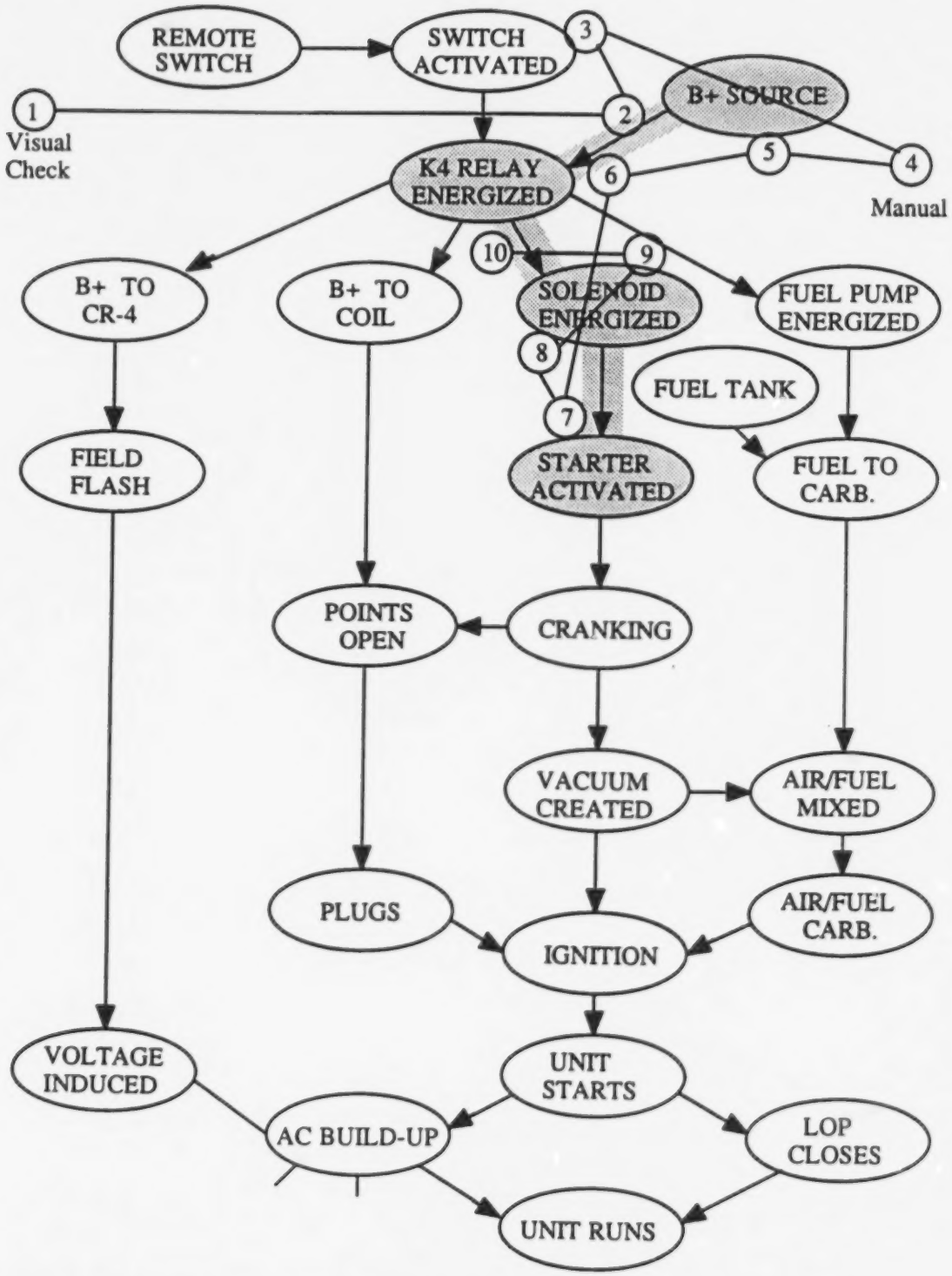


Figure 13. Control Group ss# 2 Problem Behavior Map.

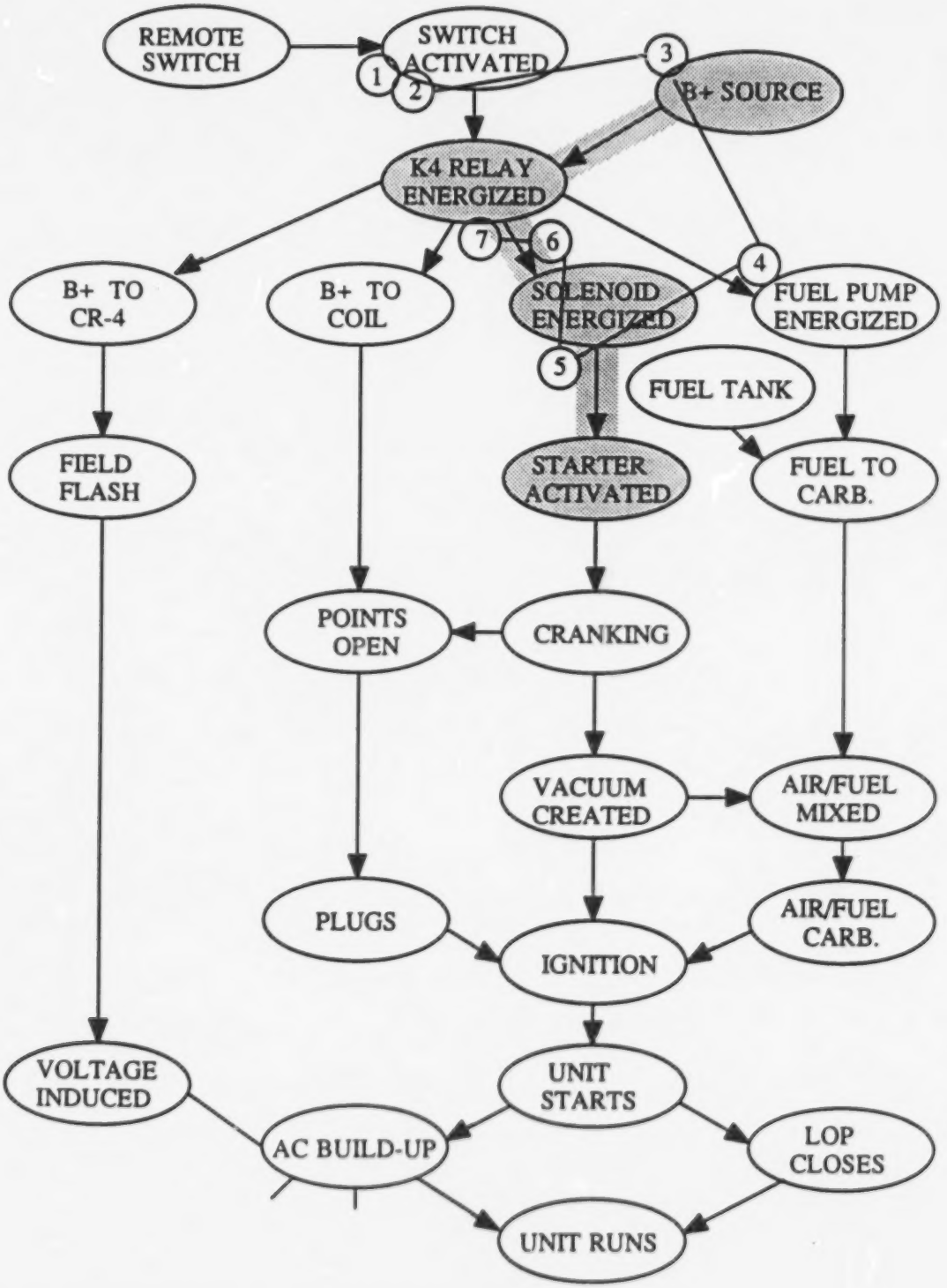


Figure 14. Control Group ss# 3 Problem Behavior Map.

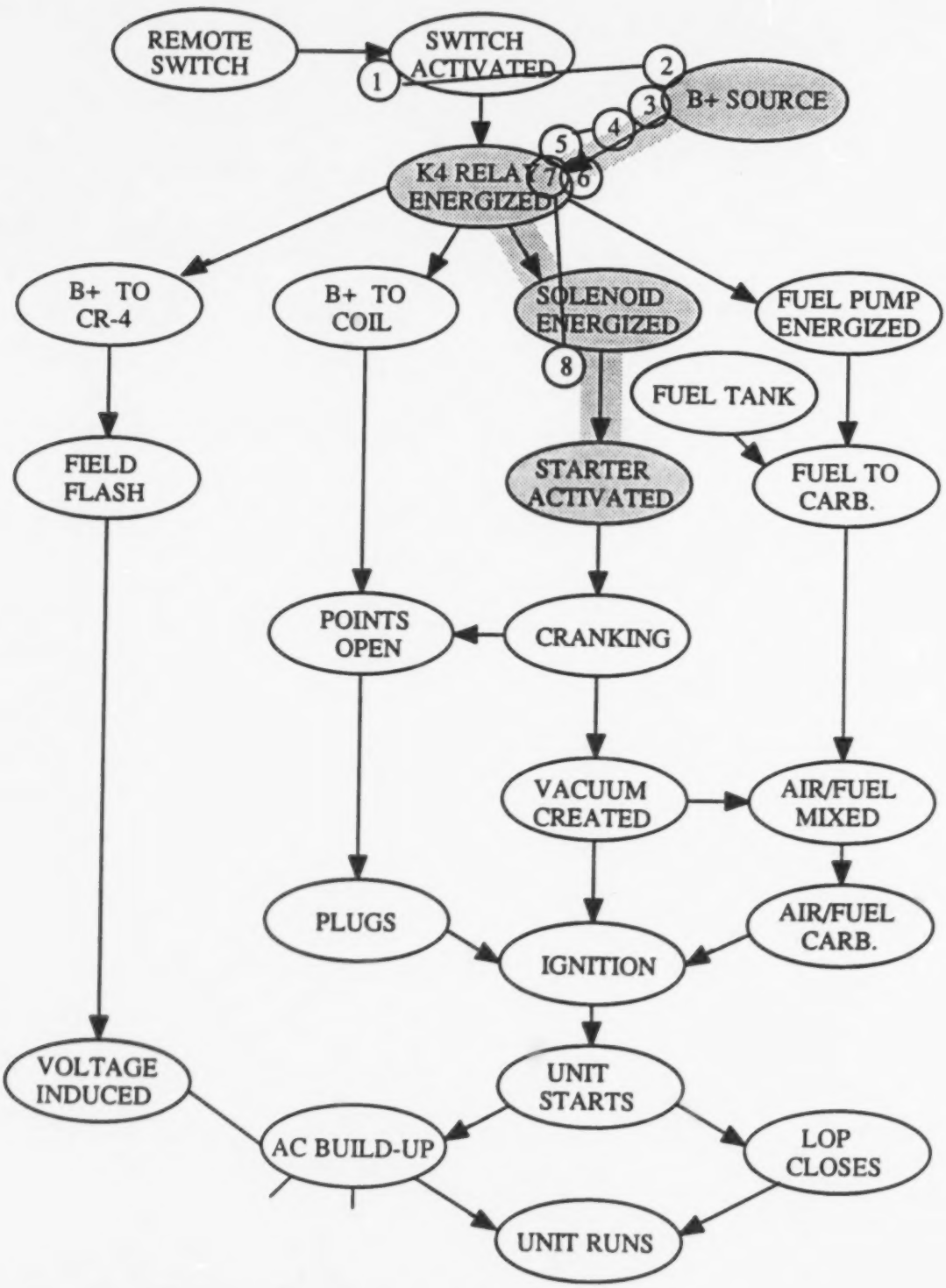


Figure 15. Control Group ss# 4 Problem Behavior Map.

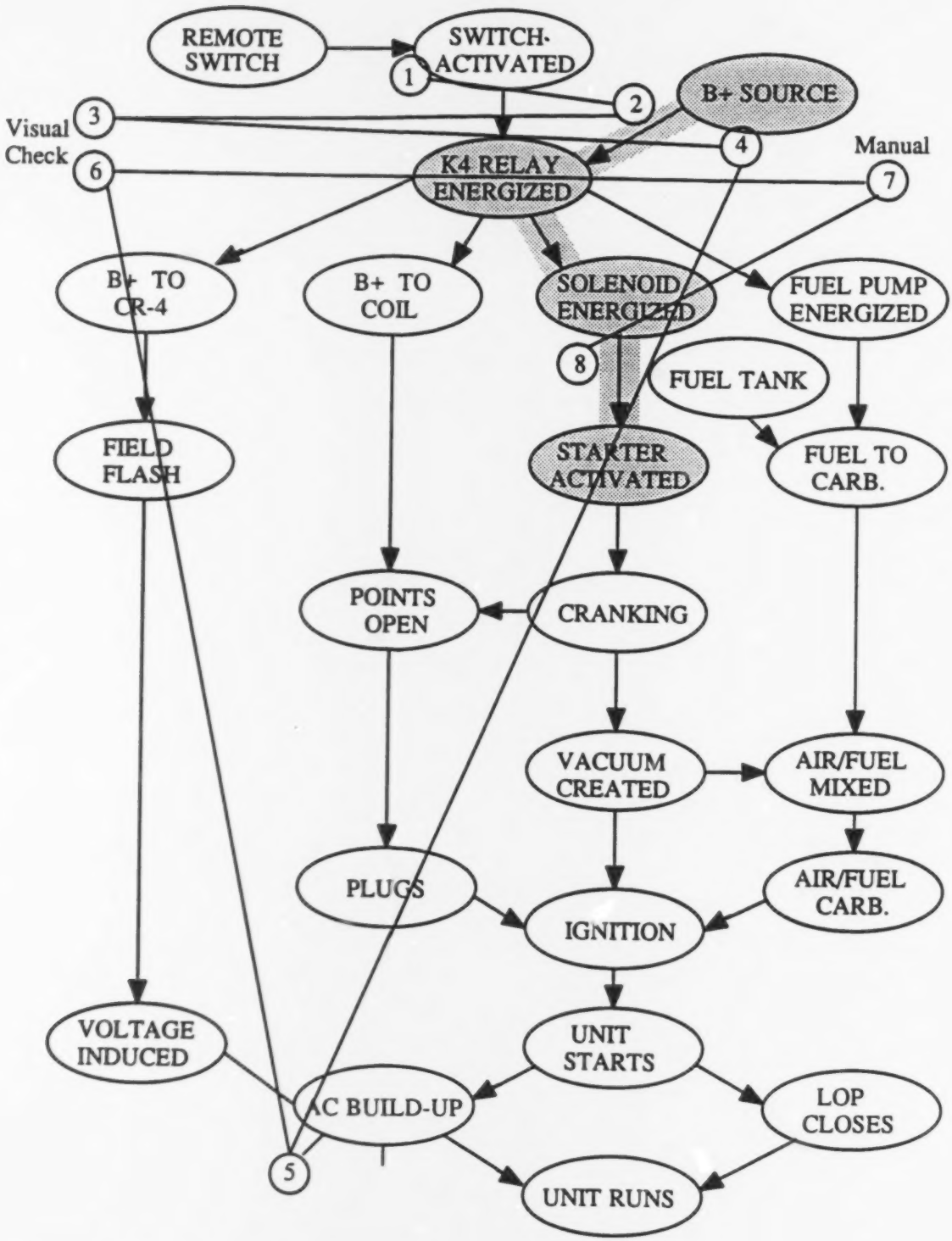


Figure 16. Control Group ss# 5 Problem Behavior Map.

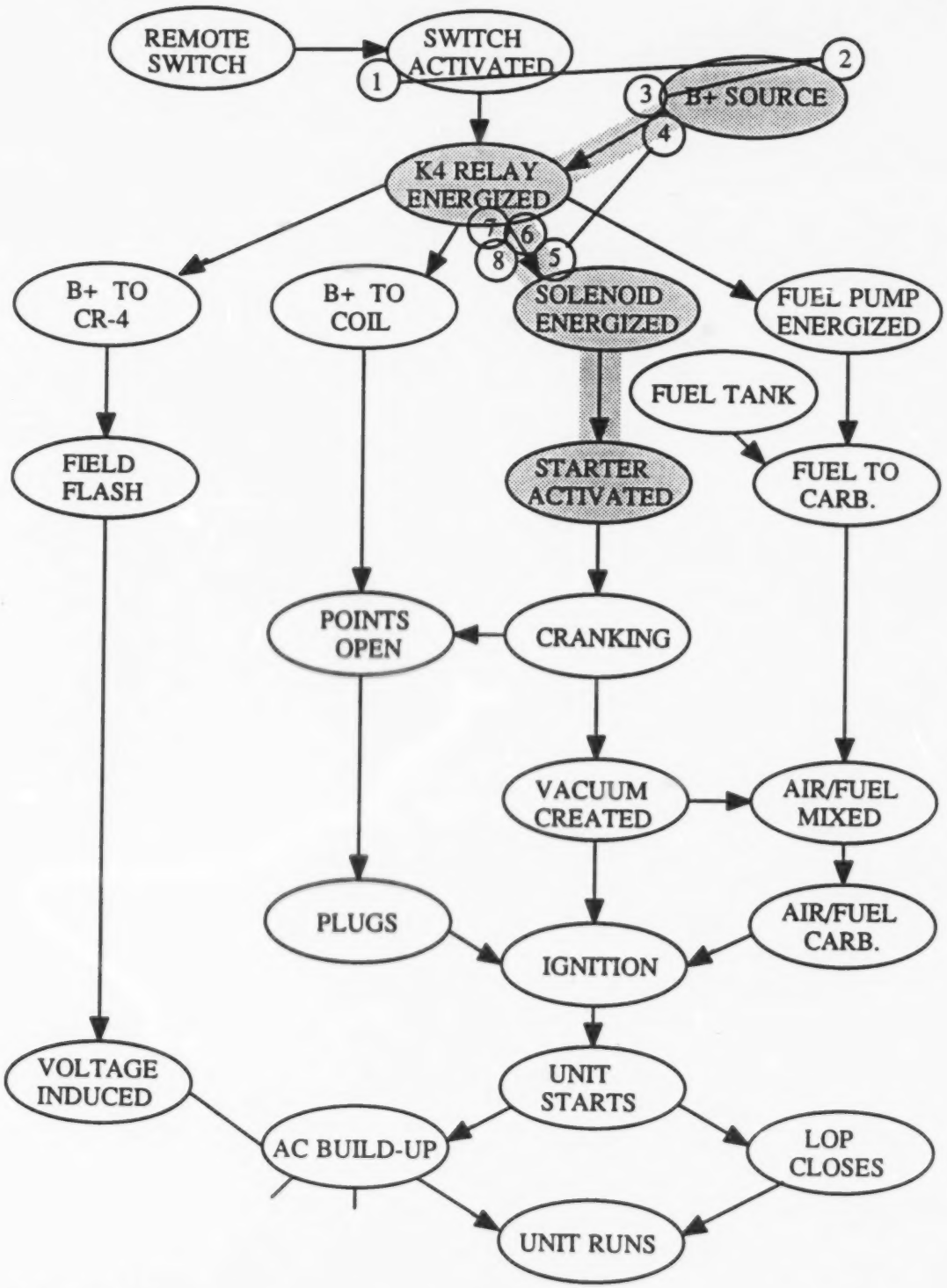


Figure 17. Control Group ss# 6 Problem Behavior Map.

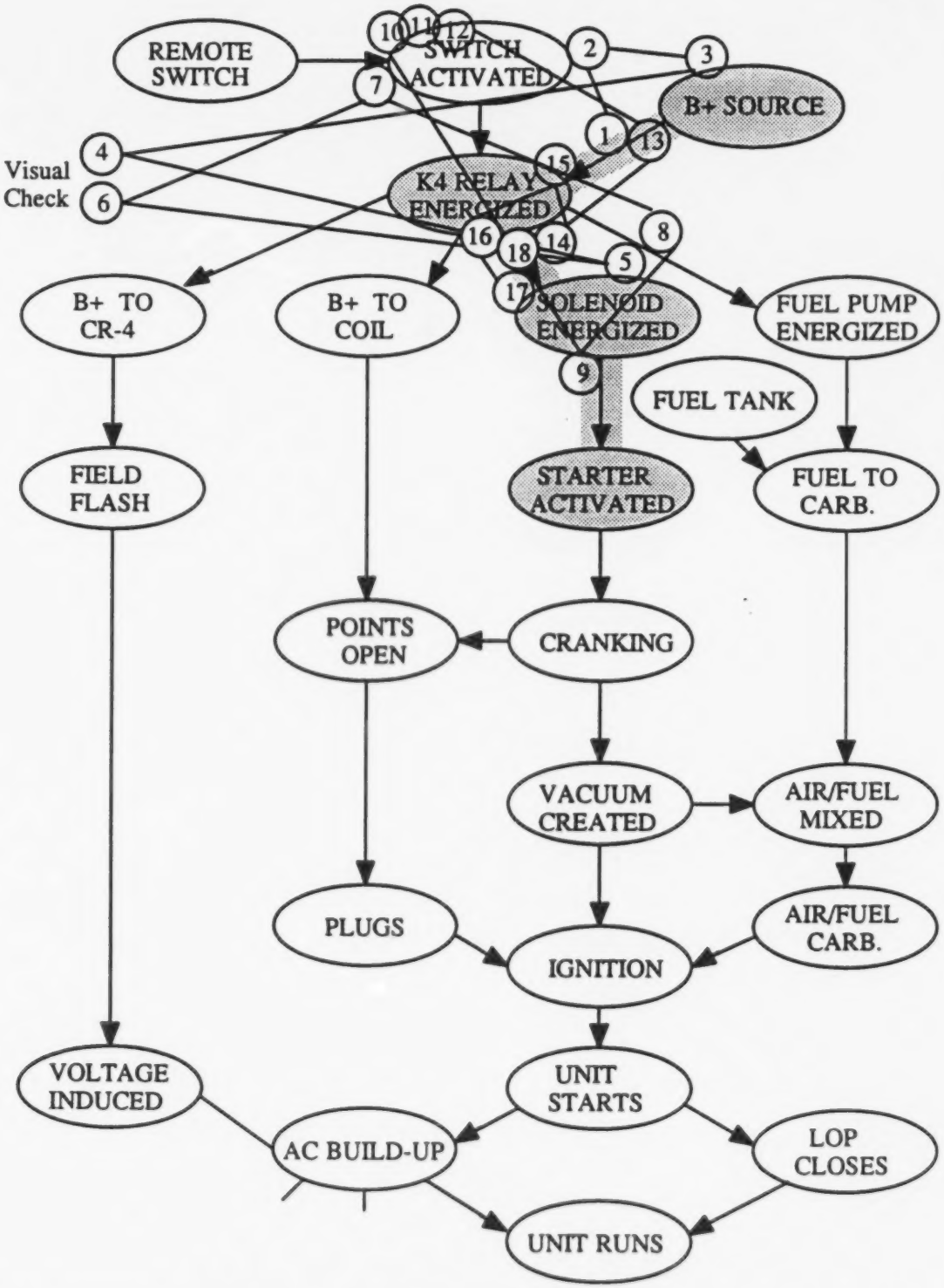


Figure 18. Control Group ss# 7 Problem Behavior Map.

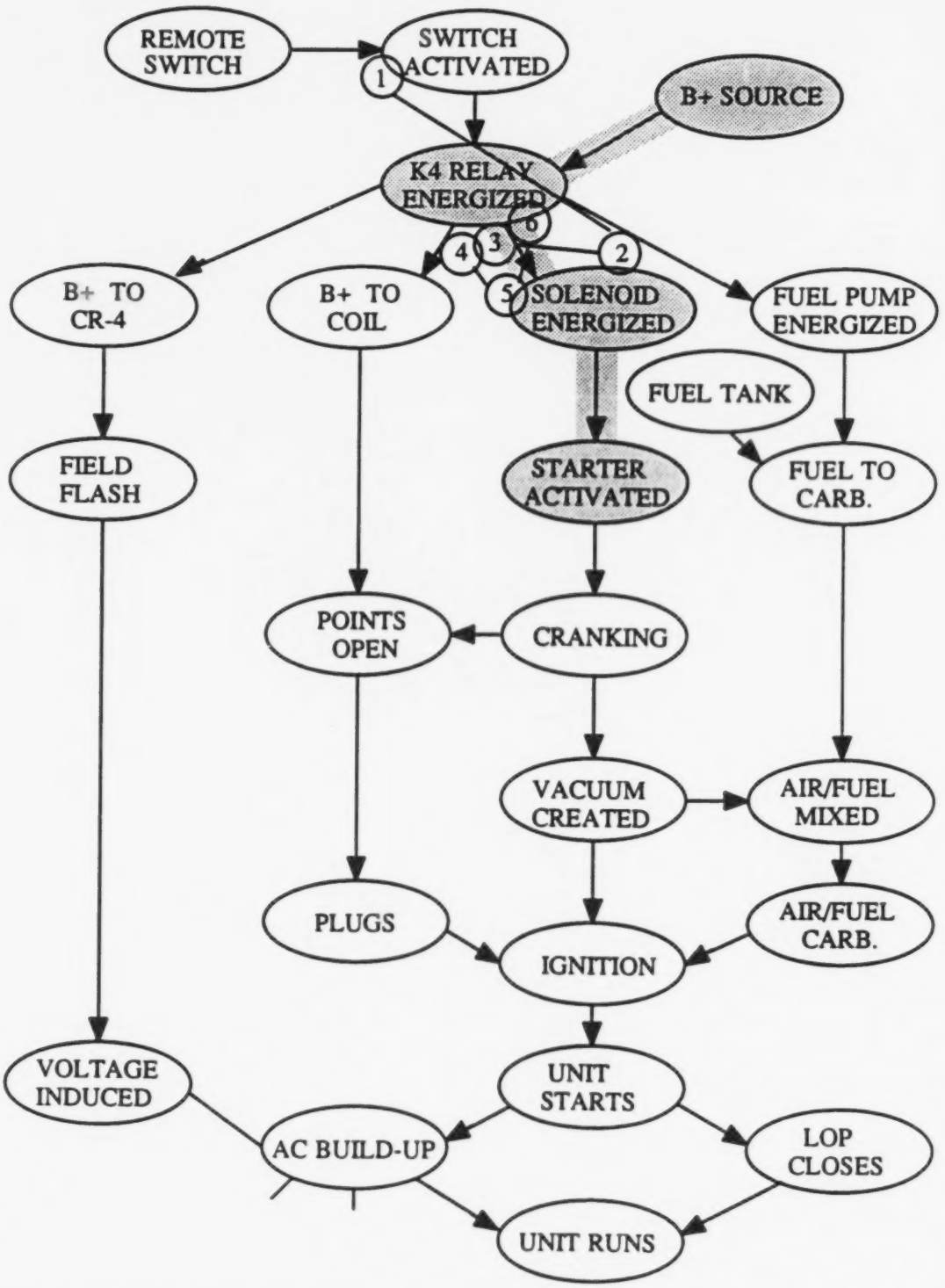


Figure 19. Control Group ss# 8 Problem Behavior Map.

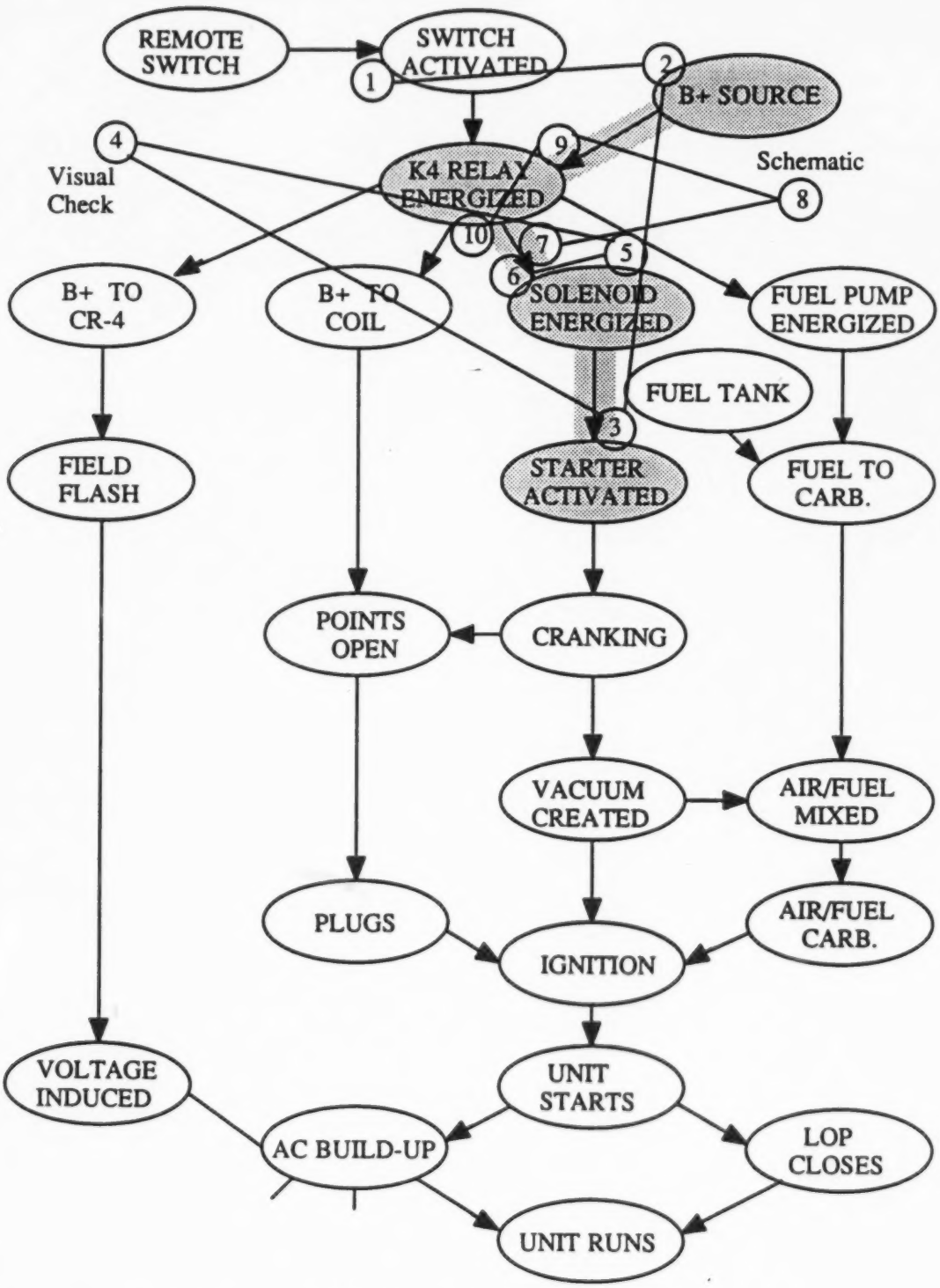


Figure 20. Control Group ss# 9 Problem Behavior Map.

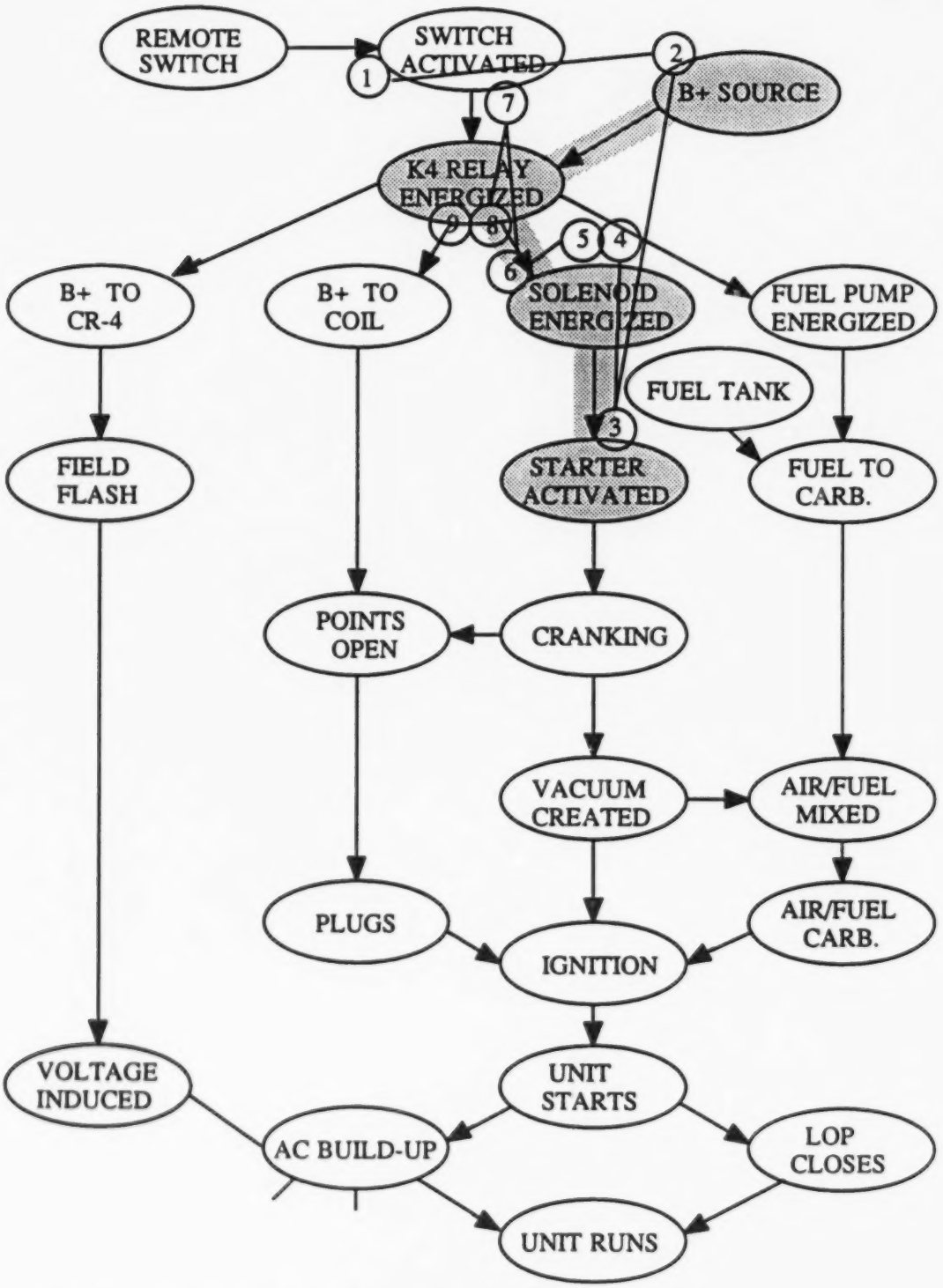


Figure 21. Control Group ss# 10 Problem Behavior Map.

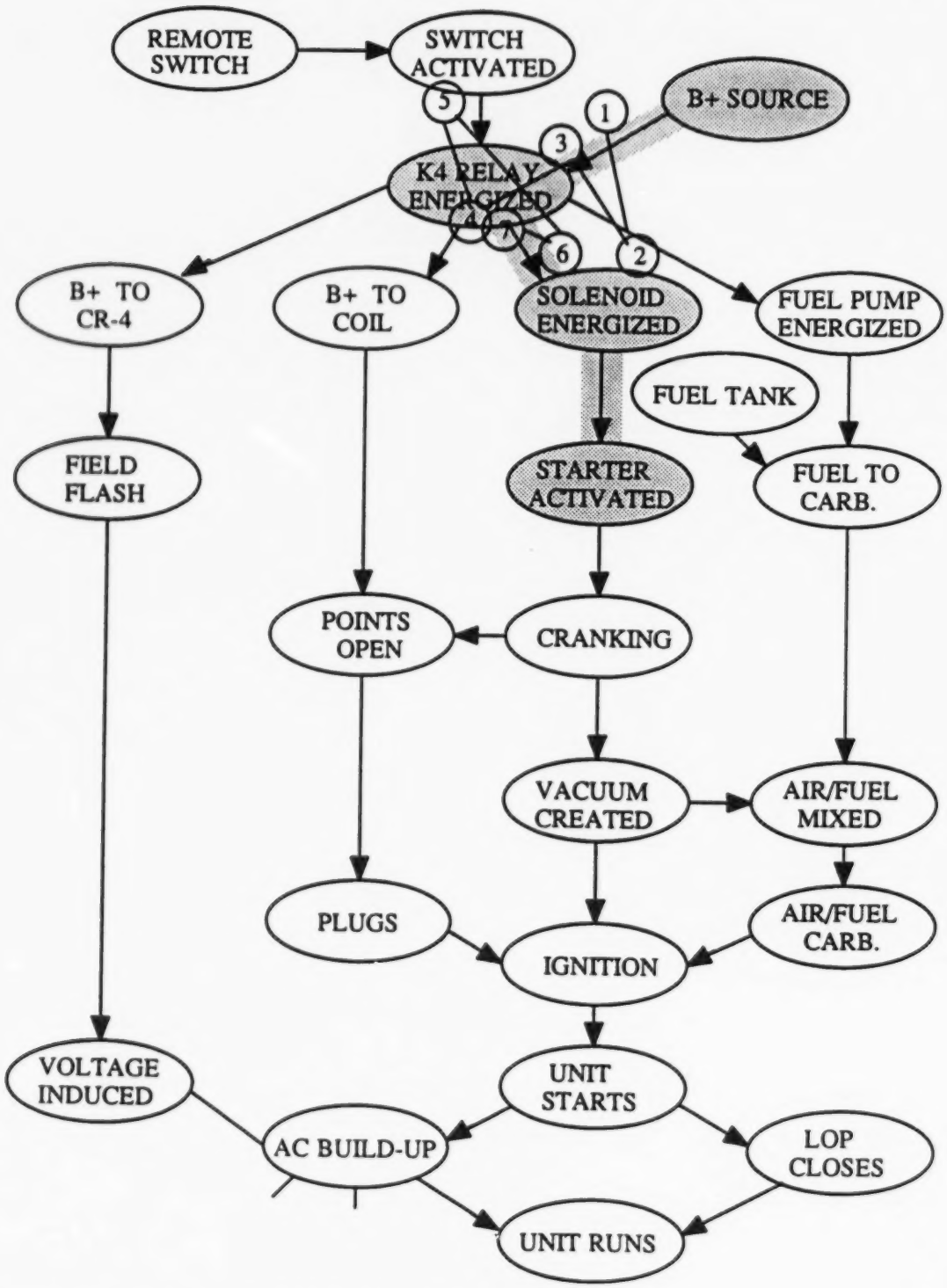


Figure 22. Control Group ss# 11 Problem Behavior Map.

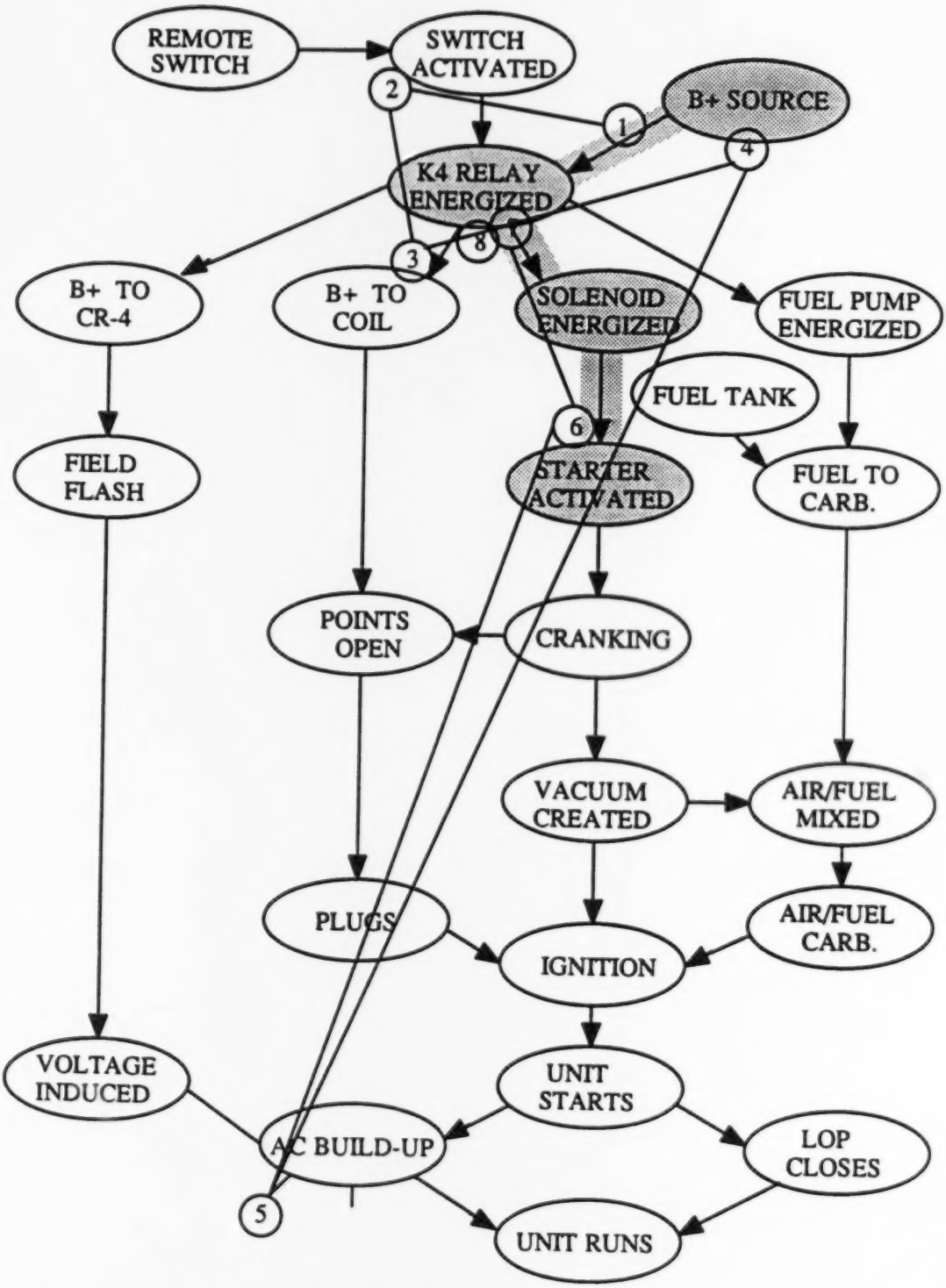


Figure 23. Control Group ss# 12 Problem Behavior Map.

APPENDIX K

EXPERIMENTAL GROUP TROUBLESHOOTING PROTOCOLS

Troubleshooting Protocol: Experimental Group Subject # 1

1. Visual check of unit.
2. Press START switch - no cranking.
3. Check voltage from K1 pin s to ground without switch pressed - 0 volts.
4. Checked voltage at K1 pin B+ - OK.
5. Jumpered battery to K1 pin SI - genset cranks.
6. Jumpered battery to K1 pin s - genset cranks.
7. Checked voltage at K1 pin s - 0 volts.

K1 bad - Wrong answer - 10 minutes.

Troubleshooting Protocol: Experimental Group Subject # 2

1. Checked oil level - OK.
2. Visually checked unit.
3. Checked battery voltage - OK.
4. Checked continuity of fuse F1 - OK.
5. Pressed START switch - no cranking.
6. Checked voltage from K1 pin s to ground - 0 volts.
7. Checked voltage from P1 pin 2 to ground - 0 volts.
8. Checked voltage from A1J1 pin 2 to ground - OK.

P1 pin 2 bad - Correct answer - **6 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 3

1. Visually checked unit.
2. Checked oil level - OK.
3. Checked continuity of fuse F1 - OK.
4. Pressed START switch - no cranking.
5. Checked voltage P1 pin 2 to ground - 0 volts.
6. Checked voltage A1J1 pin 2 to ground - OK.
7. Checked continuity P1 pin 2 to A1J1 pin 2 - infinity.

P1 pin 2 bad - Correct answer - 9 minutes.

Troubleshooting Protocol: Experimental Group Subject # 4

1. Visually checked unit.
2. Pressed START switch - no crank.
3. Checked battery voltage - OK.
4. Pressed START switch - no crank.
5. Pressed START switch - no crank.
6. Checked voltage from A1J1 pin 2 to ground with switch pressed - OK
7. Checked voltage from K1 pin s to ground - 0 volts.
8. Checked voltage from P1 pin 2 to ground - 0 volts.
9. Checked continuity from P1 pin 2 to A1J1 pin 2 - infinity.

P1 pin 2 bad - Correct answer - 15 minutes.

Troubleshooting Protocol: Experimental Group Subject # 5

1. Pressed START switch - no cranking.
2. Checked battery voltage - OK.
3. Checked continuity of fuse F1 - OK.
4. Checked voltage from P1 pin 3 to ground without switch pressed - 0 volts.
5. Checked P1 pin 5 with switch pressed - 0 volts.
6. Checked voltage from P1 pin 6 to ground - OK.
7. Checked voltage from P1 pin 3 to ground with switch pressed - OK.
8. Checked voltage from P1 pin 5 to ground with switch pressed - 0 volts.
9. Checked K1 pin s to ground with switch pressed - 0 volts.
10. Checked J1 pin 2 to ground with switch pressed - OK.
11. Checked P1 pin 2 to ground with switch pressed - 0 volts.

P1 pin 2 bad - Correct answer - **10 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 6

1. Visually checked unit - OK.
2. Pressed START switch - no cranking.
3. Checked continuity of fuse F1 - OK.
4. Checked A1J1 pin 2 to ground with switch pressed - OK.
5. Checked voltage from K1 pin s to ground with switch pressed - 0 volts.
6. Checked voltage from P1 pin 2 to ground with switch pressed 0 volts.

P1 pin 2 bad - Correct answer - **12 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 7

1. Pressed START switch - no cranking.
2. Checked continuity of fuse F1 - OK.
3. Visually checked unit.
4. Checked voltage from K1 B+ to ground - OK.
5. Checked voltage from A1J1 pin 6 to ground - OK.
6. Checked voltage from A1J1 pin 6 to A1J1 pins 7 & 8 - OK.
7. Visually checked P1 plug - Nothing abnormal.
8. Checked voltage at P1 pin 2 with switch pressed - OK.
9. Checked voltage from A1J1 pin 3 with switch pressed - OK.
10. Checked voltage from K1 pin s to ground with switch pressed - 0 volts.
11. Checked voltage from K1 pin SI to ground with switch pressed - 0 volts.

K1 bad - Wrong answer - 8 minutes.

Troubleshooting Protocol: Experimental Group Subject # 8

1. Verified problem - no cranking.
2. Checked battery voltage - OK.
3. Checked voltage from P1 pin 6 to ground - OK.
4. Checked switch for "power."
5. Checked voltage from starter terminal to ground with switch pressed - 0 volts.
6. Checked voltage from K1 pin SI to ground with switch pressed - 0 volts.
7. Checked voltage from K1 B+ to ground - OK.
8. Checked voltage from K1 pin s to ground with switch pressed 0 volts.
9. Visually checked plug P1.

P1 pin 2 bad - Correct answer - **9 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 9

1. Checked oil level - OK.
2. Checked battery voltage - OK.
3. Pressed START switch - no cranking.
4. Checked voltage from P1 pin 6 to P1 pins 7 & 8 - OK.
5. Checked voltage from P1 pin 6 to ground - OK.
6. Checked P1 pin 2 to ground with switch pressed - 0 volts.

Circuit Board bad - Wrong part - 4 minutes.

Troubleshooting Protocol: Experimental Group Subject # 10

1. Checked oil level - OK.
2. Pressed START switch - no crank.
3. Checked voltage from K1 pin s to ground with switch pressed - 0 volts.
4. Checked voltage from A1J1 pin 2 to ground with switch pressed - OK.
5. Visually checked plug P1 - pin 2 bad.

P1 pin 2 bad - Correct answer - **11 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 11

1. Pressed START switch - no cranking.
2. Checked battery voltage - OK.
3. Checked continuity from S1 pin 1 to ground - infinity.
4. Checked continuity from S1 pin 2 to ground - infinity, with switch pressed to STOP position - 0 ohms.
5. Checked continuity from S1 pin 3 to ground - infinity, with switch pressed to START position - 0 ohms.
6. Checked continuity fro A1J1 pin 2 to P1 pin 2 - infinity.

P1 pin 2 bad - Correct answer - **21 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 12

1. Checked oil level - OK.
2. Visually checked unit.
3. Checked continuity of fuse F1 - OK.
4. Pressed START switch - no cranking.
5. Checked battery voltage - OK.
6. Checked continuity of ground from genset to battery - OK.
7. Checked voltage from K1 pin B+ to K1 pin s with switch pressed - 12 volts.

Solenoid K1 shorted - Wrong answer - 8 minutes.

Troubleshooting Protocol: Experimental Group Subject # 13

1. Pressed START switch - no cranking.
2. Checked voltage from P1 pin 6 to ground - OK.
3. Checked voltage from P1 pin 2 to ground with switch pressed - 0 volts.
4. Checked voltage from K1 pin s to ground with switch pressed - 0 volts.
5. Checked voltage from K1 pin s to ground with switch pressed - 0 volts.

Circuit Board bad - Wrong answer - 7 minutes.

Troubleshooting Protocol: Experimental Group Subject # 14

1. Pressed START switch - no cranking.
2. Visually checked P1 connector.
3. Checked voltage from P1 pin 6 to ground - OK.
4. Checked voltage from P1 pin 2 to ground with switch pressed - 0 volts.
5. Checked voltage from A1J1 pin 2 to ground with switch pressed - OK.

P1 pin 2 bad - Correct answer - **5 minutes.**

Troubleshooting Protocol: Experimental Group Subject # 15

1. Checked oil level - OK.
2. Visually checked unit - OK.
3. Checked continuity of fuse F1 - OK.
4. Pressed START switch - no cranking.
5. Checked battery voltage - OK.
6. Checked battery B+ connection to genset - OK.
7. Checked voltage from K1 pin SI to ground with switch pressed - 0 volts.
8. Checked voltage from K1 pin s to ground with switch pressed - 0 volts.
9. Visually checked P1 - bad pin 2.

P1 pin 2 bad - Correct answer - 5 minutes.

Troubleshooting Protocol: Experimental Group Subject # 16

1. Pressed START switch - no cranking.
2. Checked continuity from A1J1 to P1 pins - pins 1, 3-8 OK, pin 2 bad.
3. Checked voltage from A1J1 pin 2 to ground with switch pressed - OK.

P1 pin 2 bad - Correct answer - 5 minutes.

APPENDIX L

EXPERIMENTAL GROUP PROBLEM BEHAVIOR MAPS WITH THE PROBLEM SPACE HIGHLIGHTED

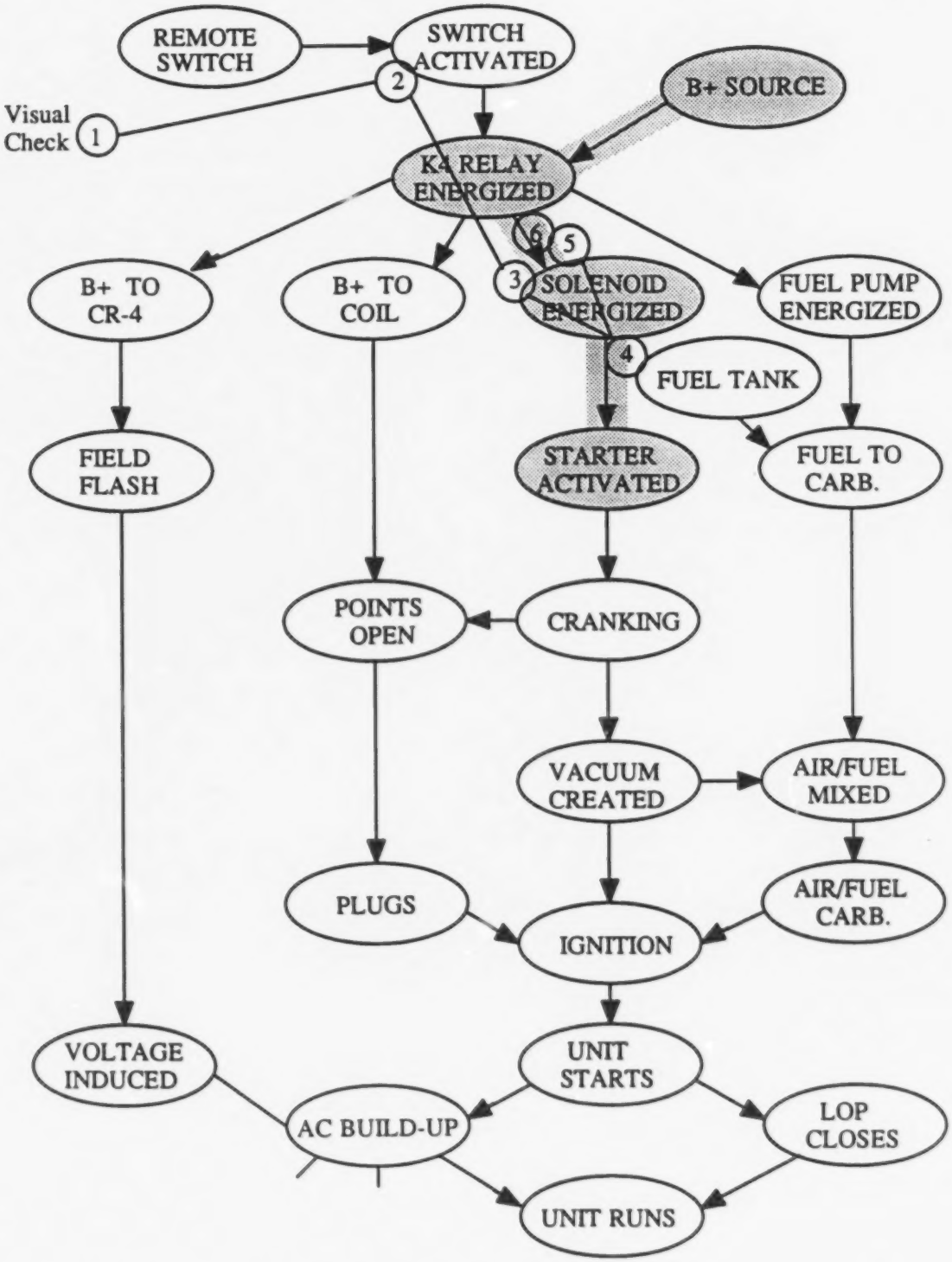


Figure 24. Experimental Group ss# 1 Problem Behavior Map

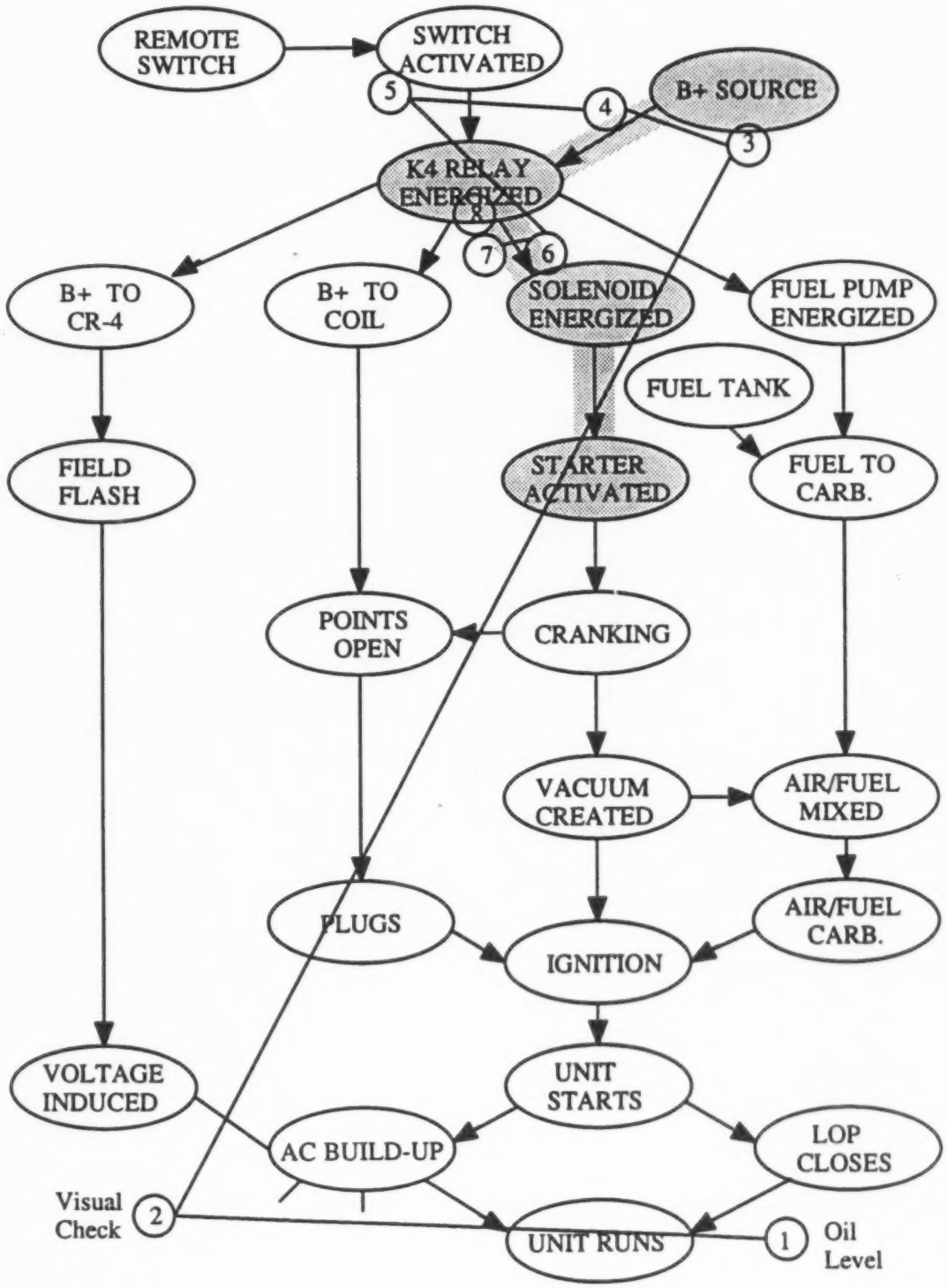


Figure 25. Experimental Group ss# 2 Problem Behavior Map

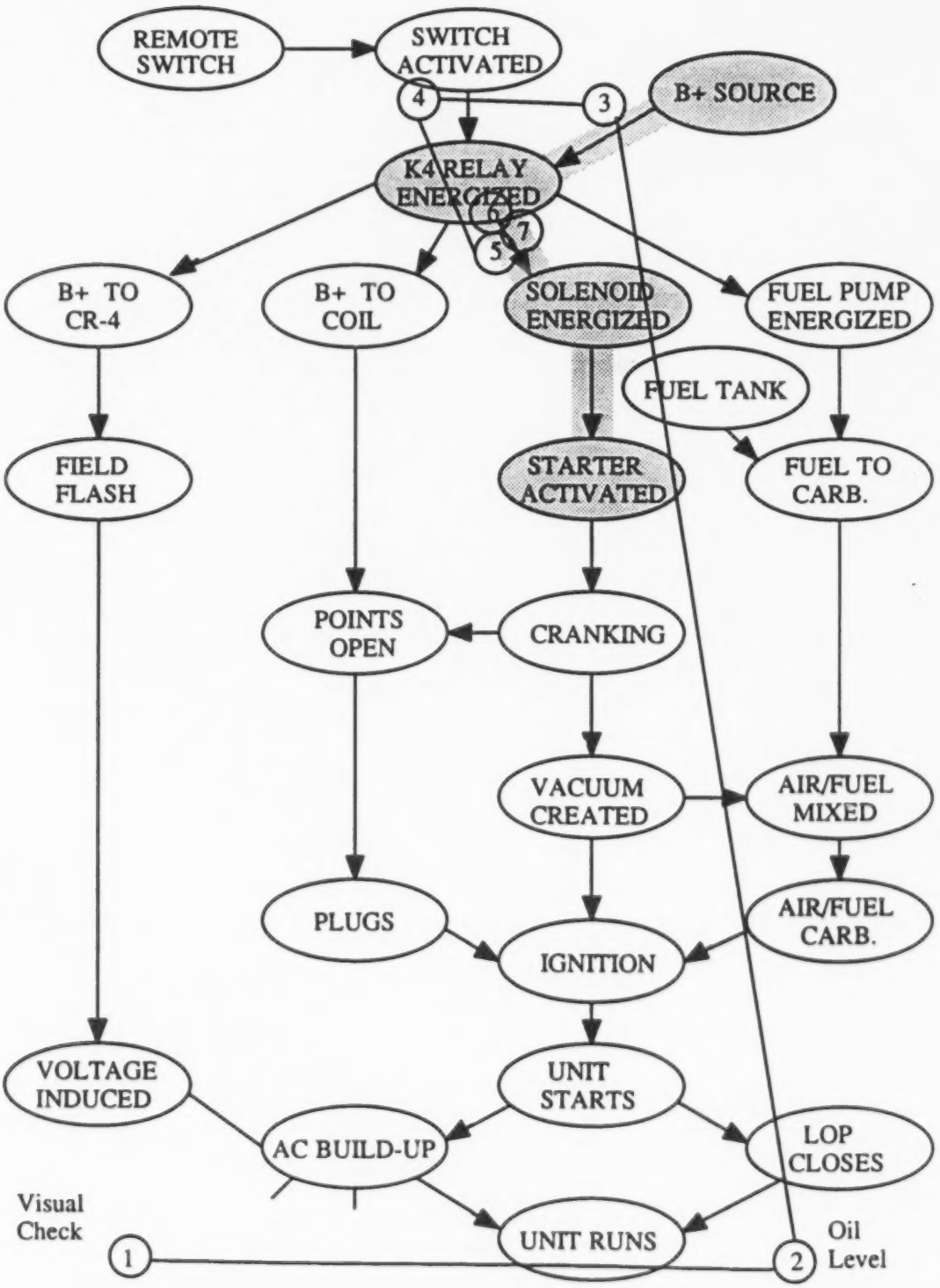


Figure 26. Experimental ss# 3 Problem Behavior Map

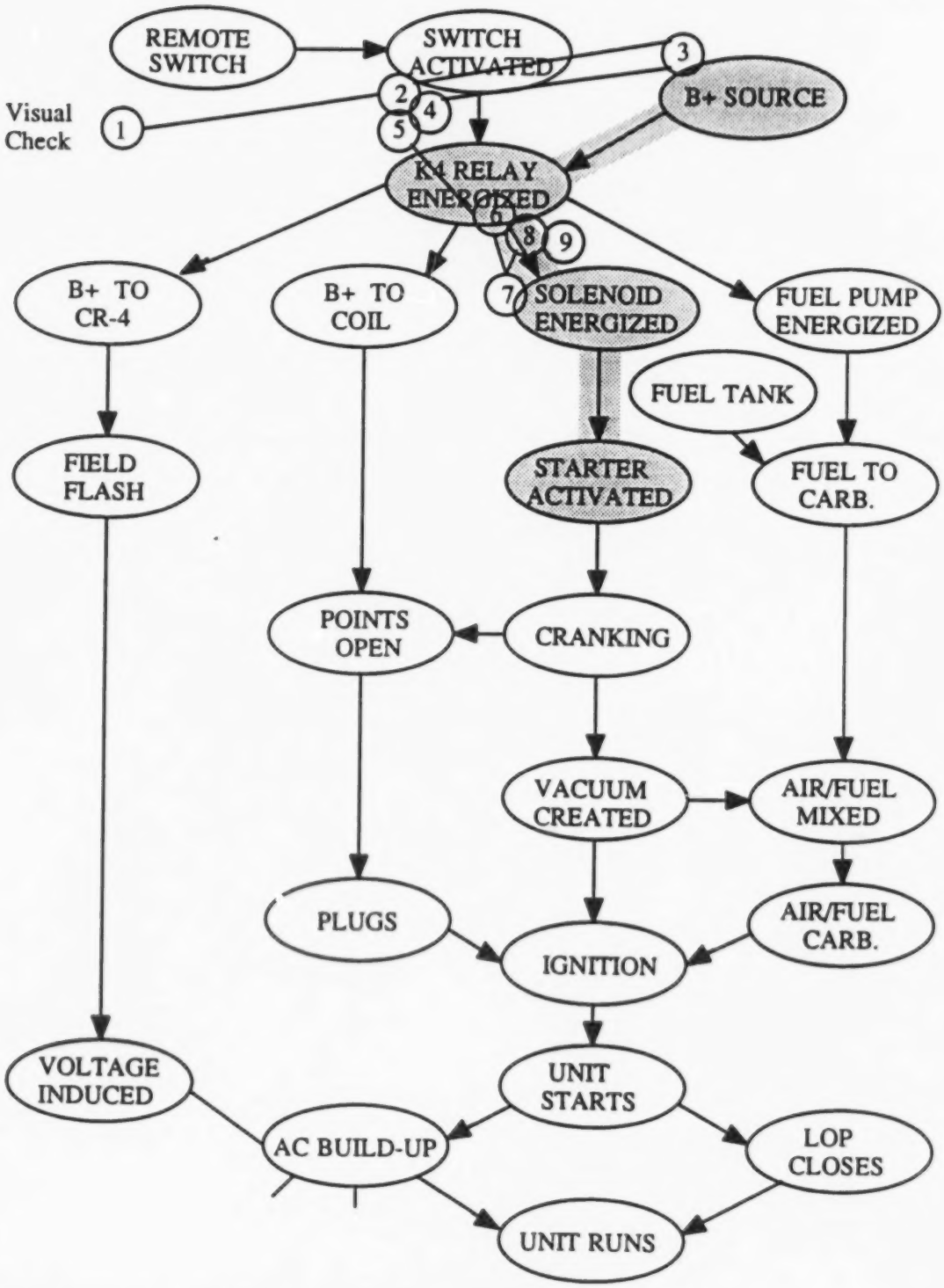


Figure 27. Experimental ss# 4 Problem Behavior Map

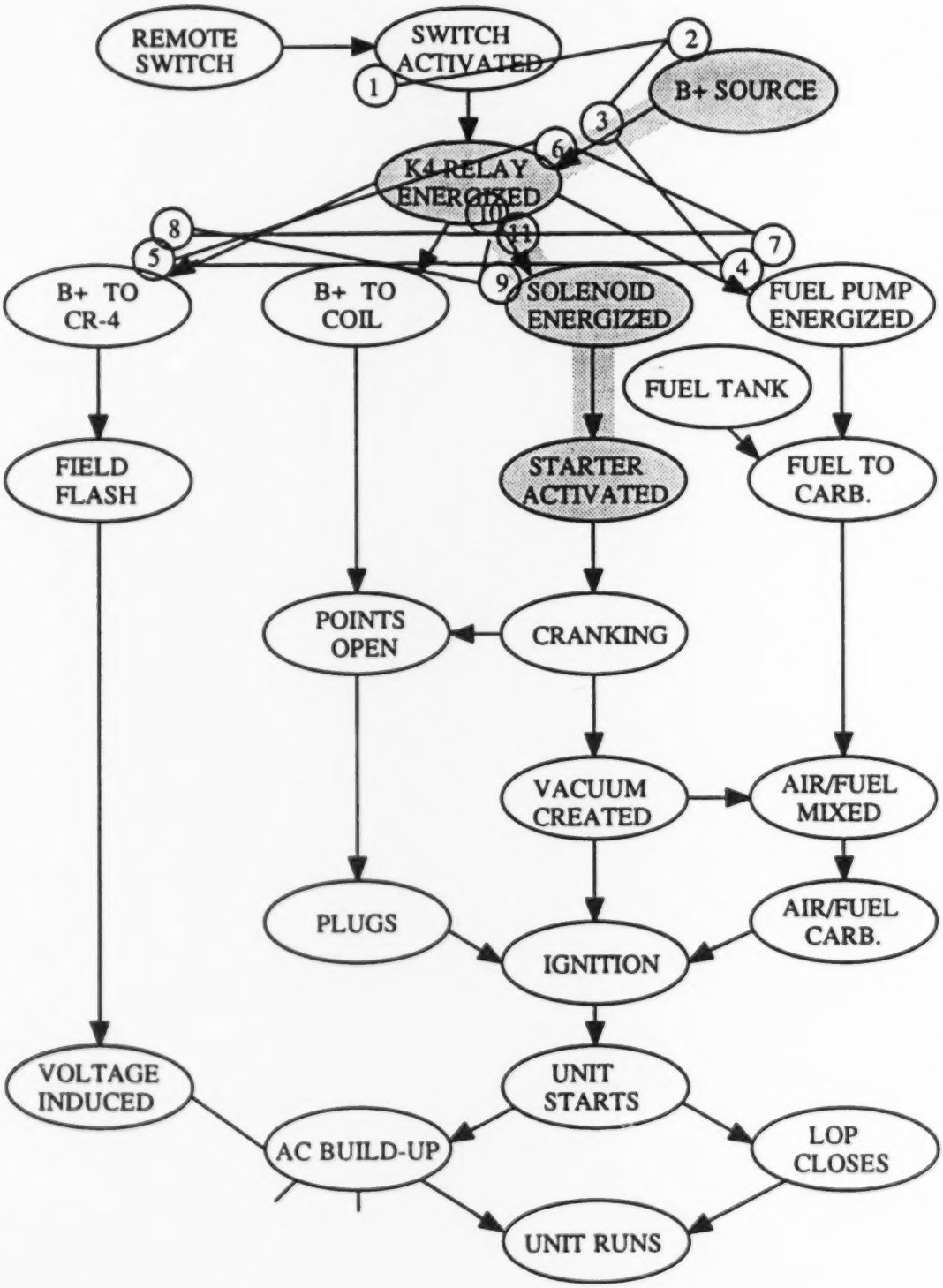


Figure 28. Experimental ss# 5 Problem Behavior Map

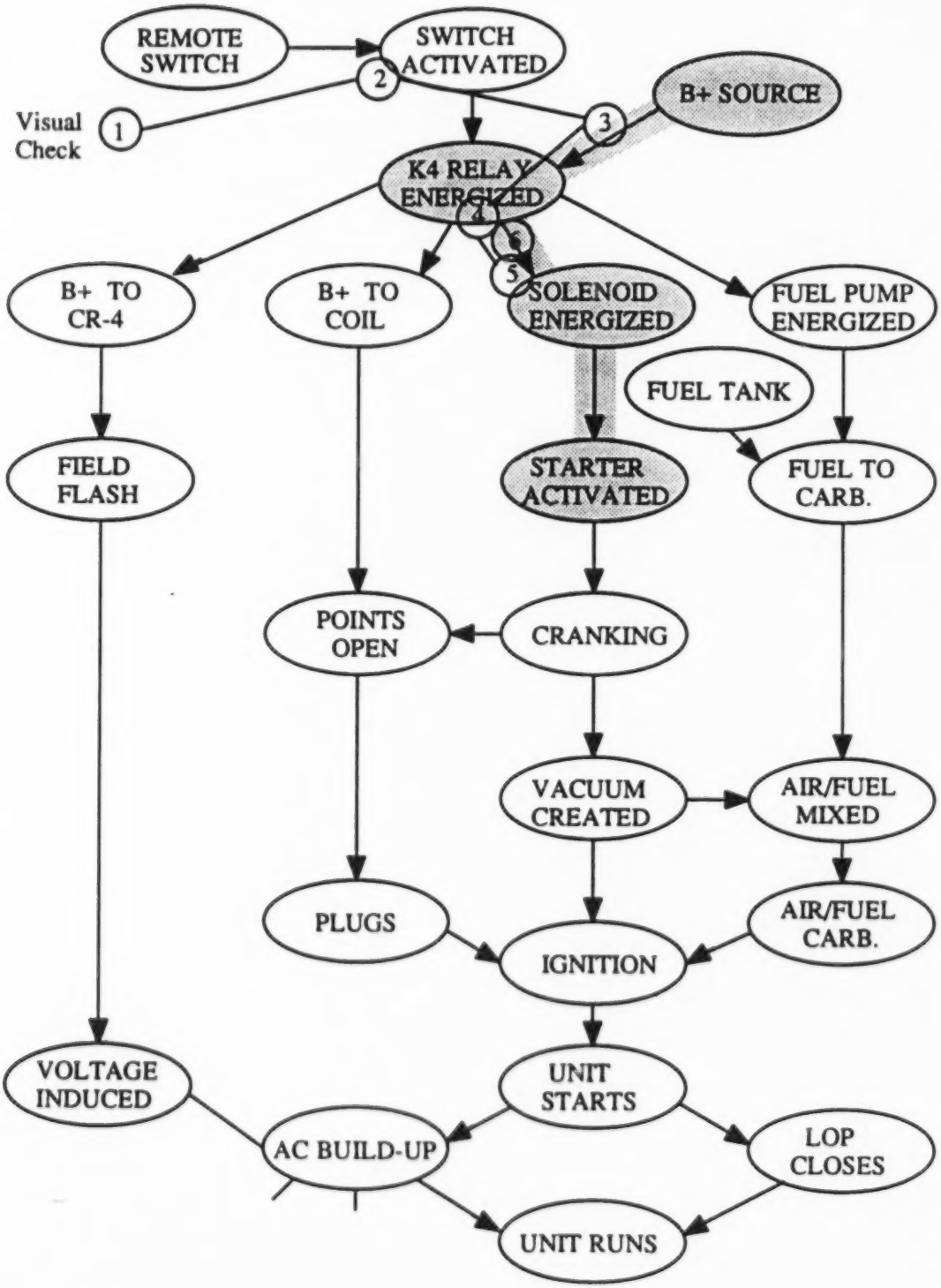


Figure 29. Experimental ss# 6 Problem Behavior Map

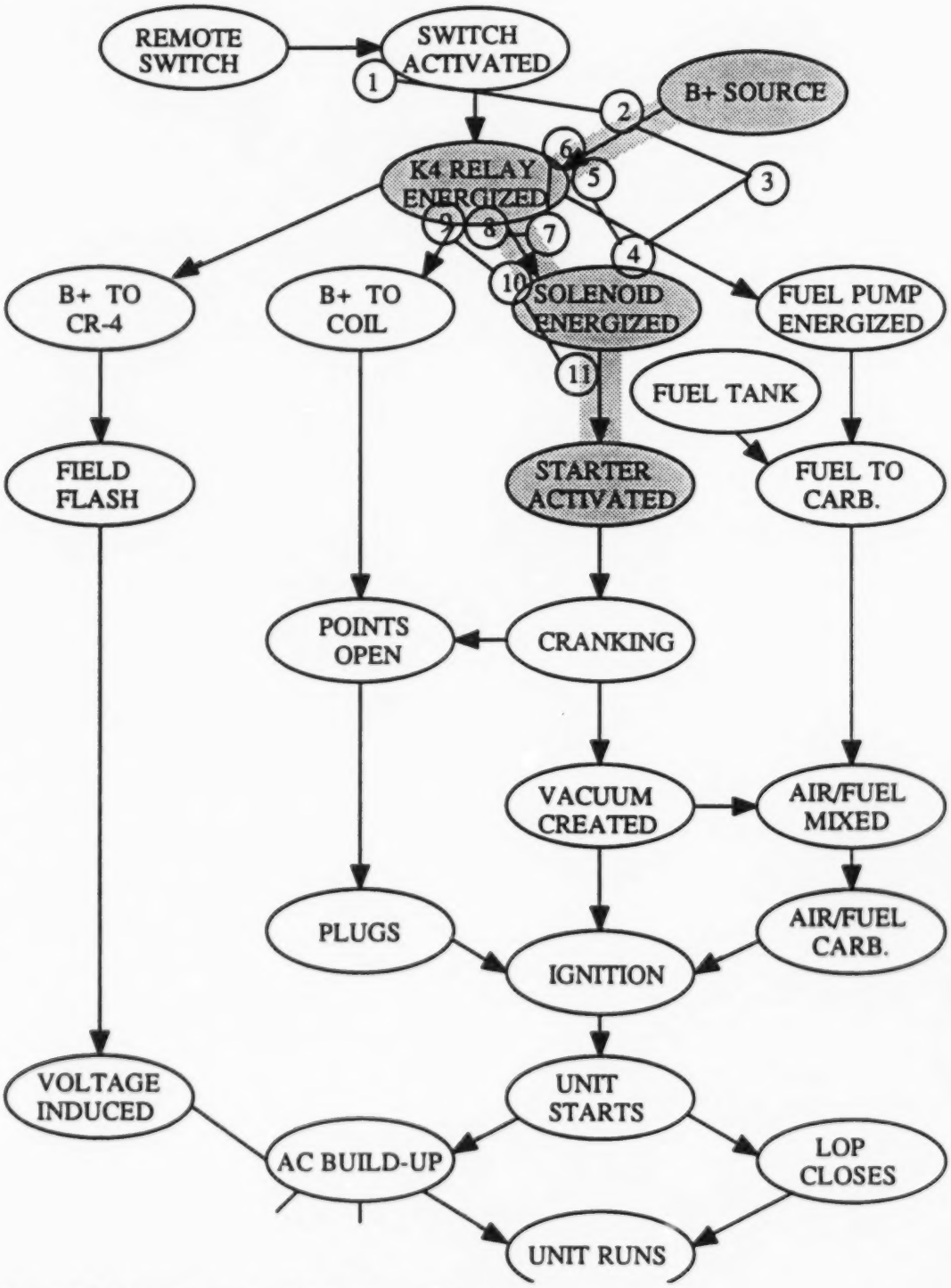


Figure 30. Experimental ss# 7 Problem Behavior Map

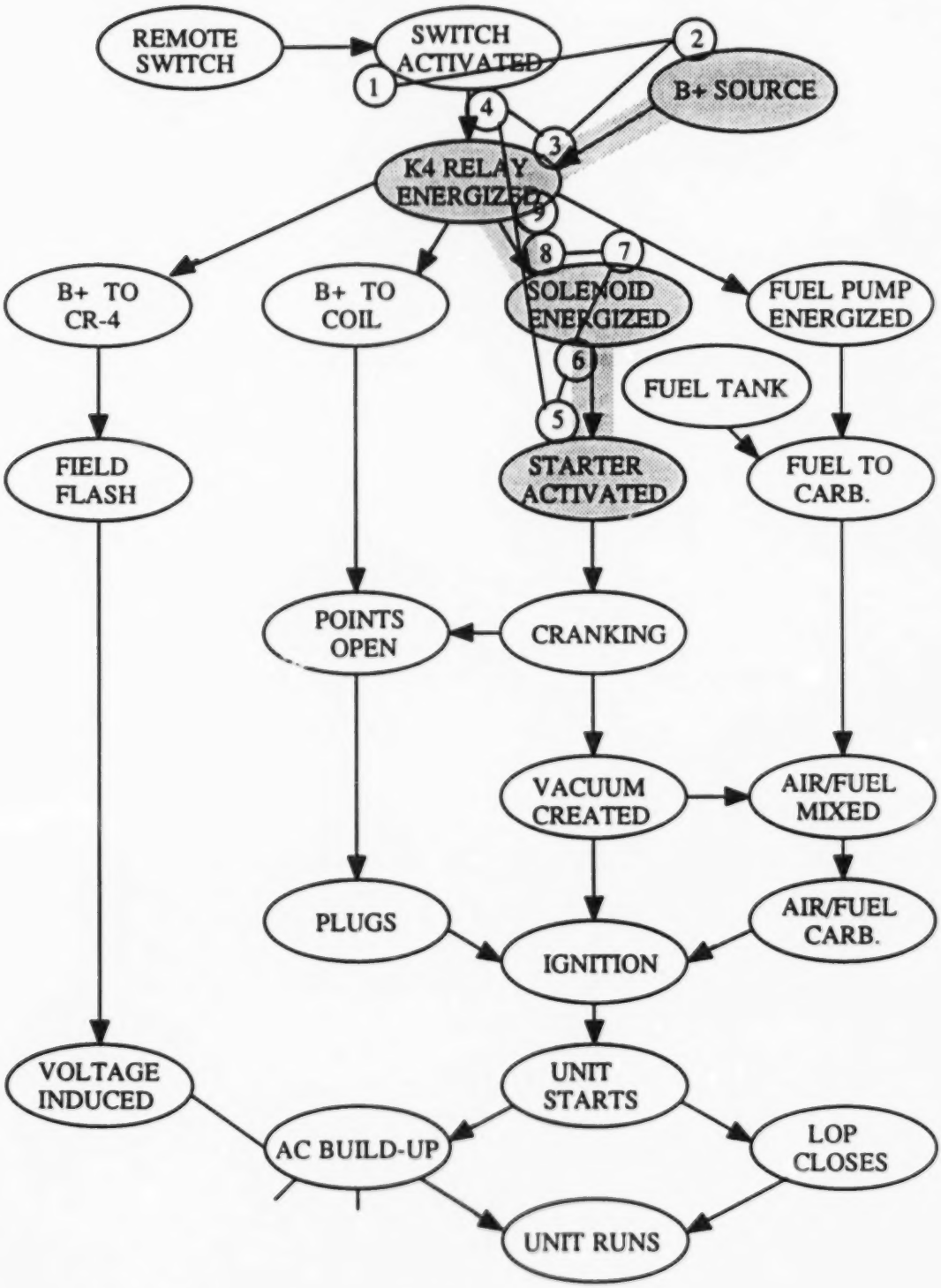


Figure 31. Experimental ss# 8 Problem Behavior Map

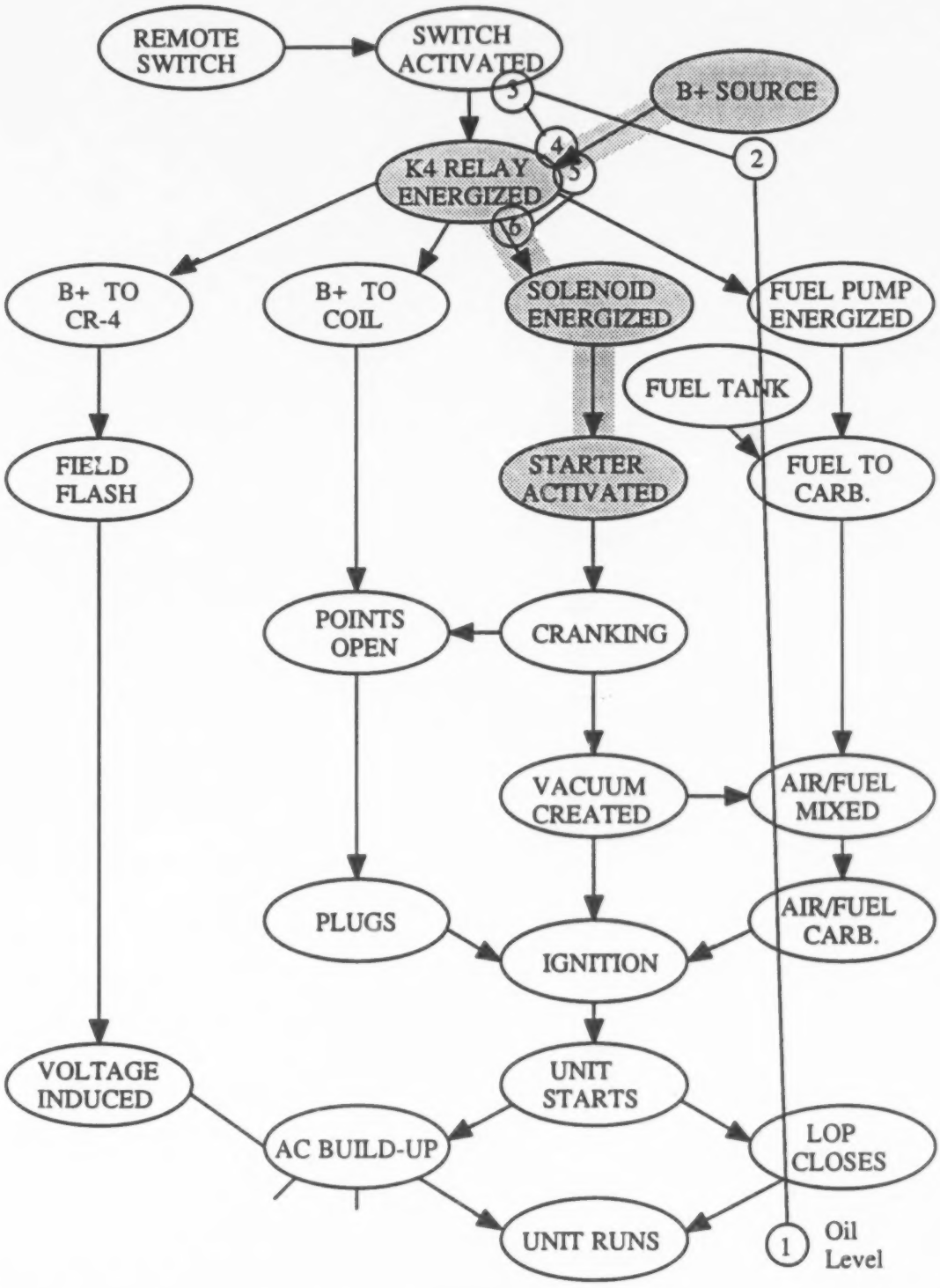


Figure 32. Experimental ss# 9 Problem Behavior Map

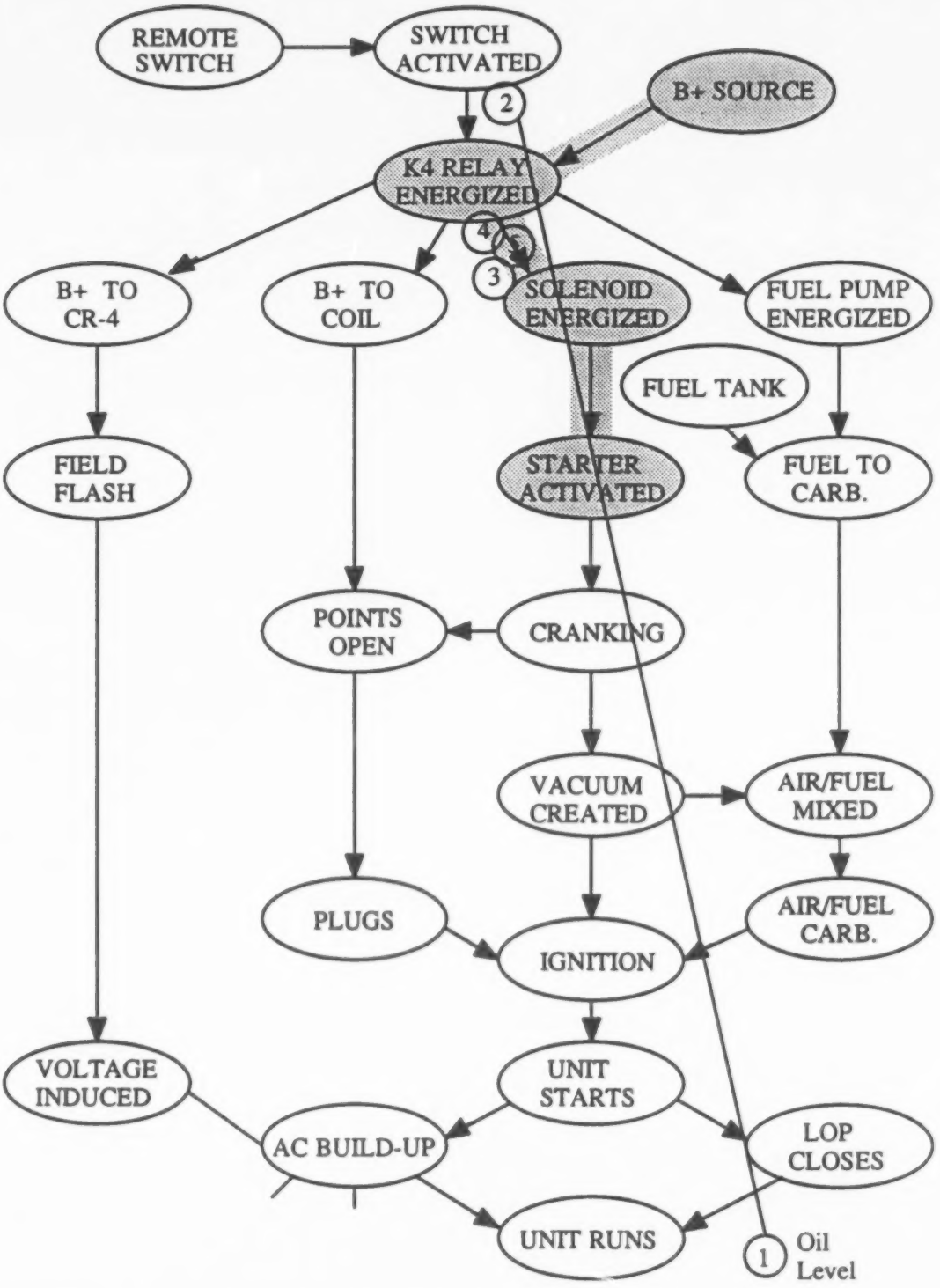


Figure 33. Experimental ss# 10 Problem Behavior Map

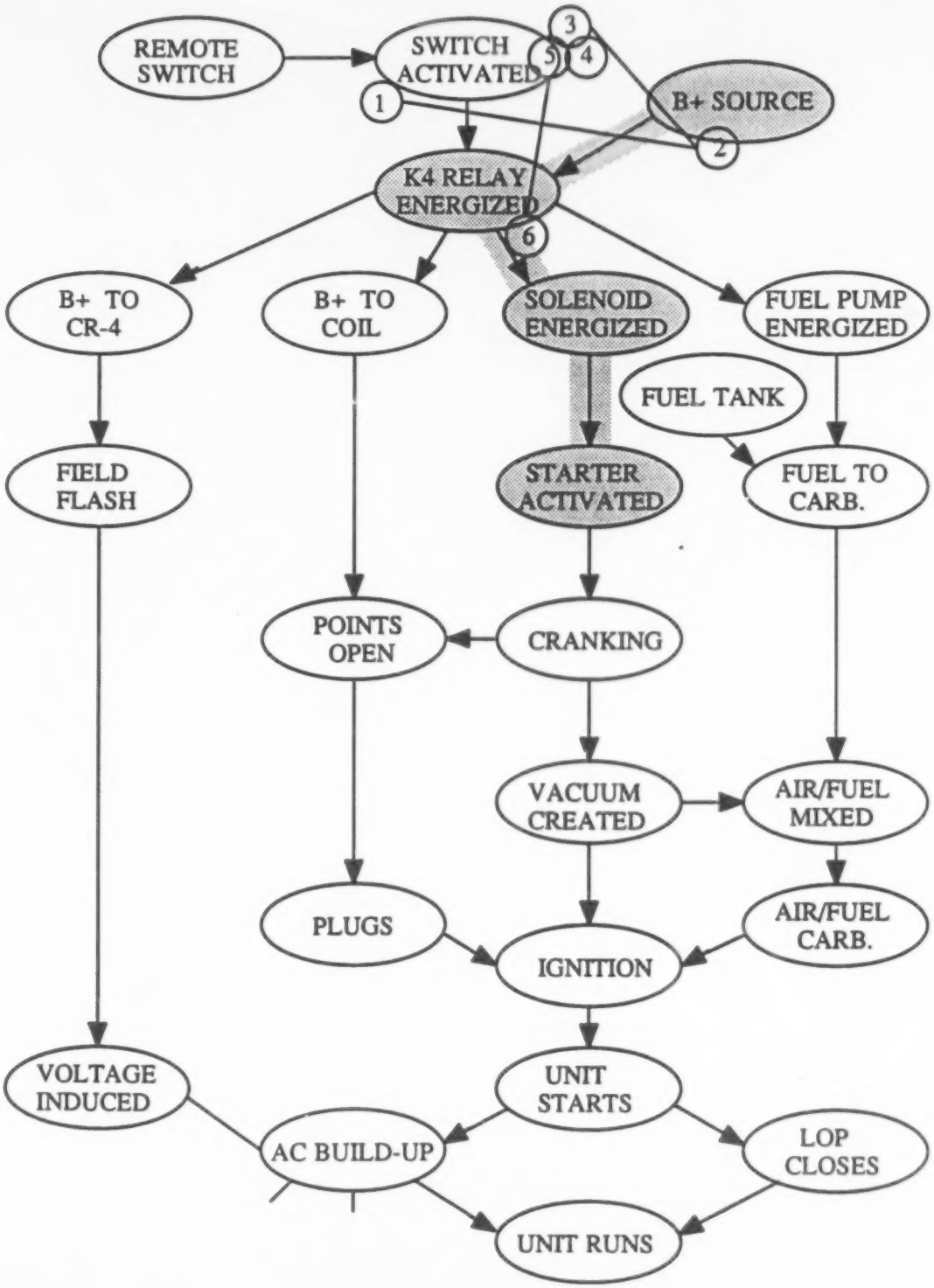


Figure 34. Experimental ss# 11 Problem Behavior Map

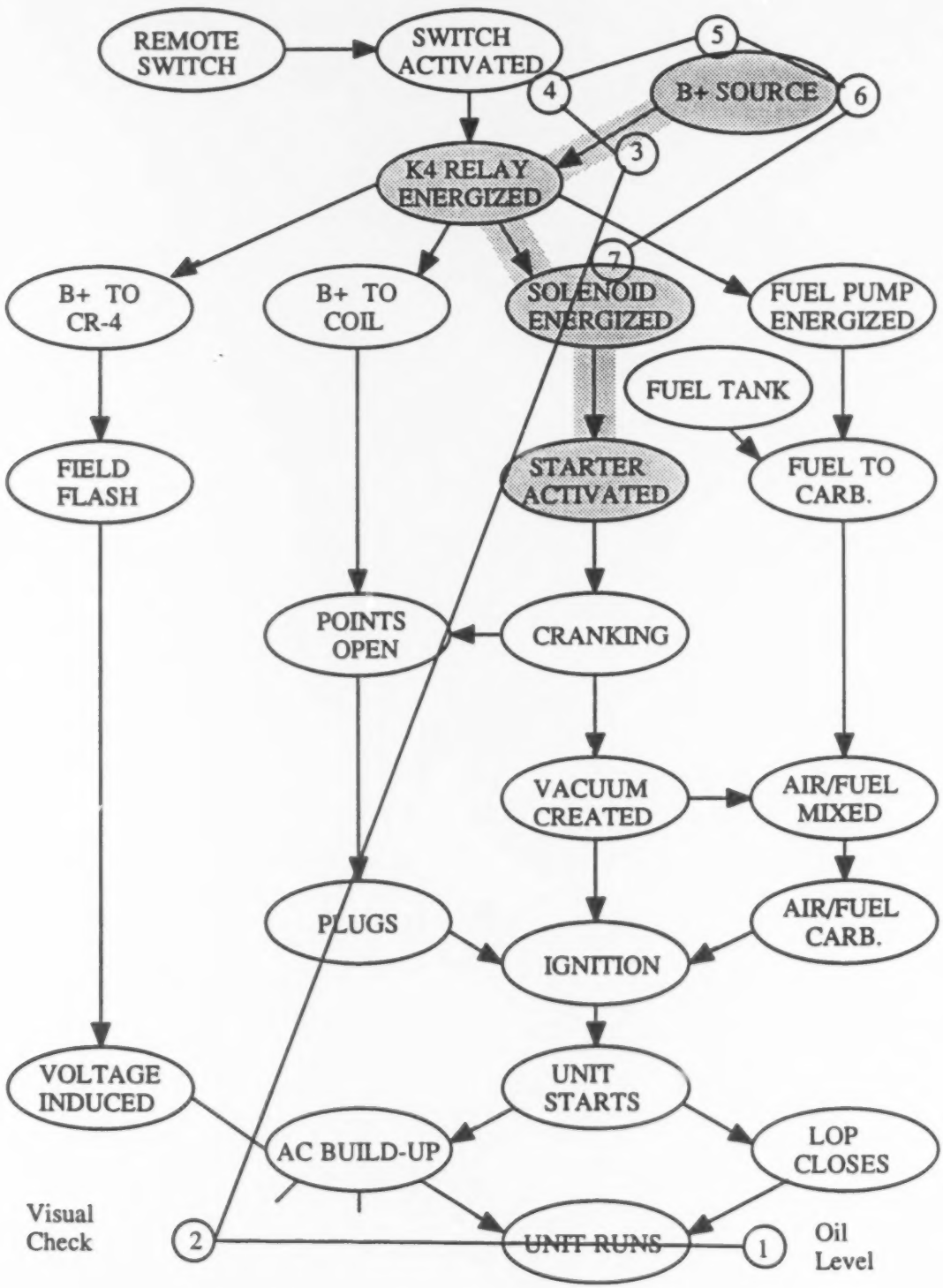


Figure 35. Experimental ss# 12 Problem Behavior Map

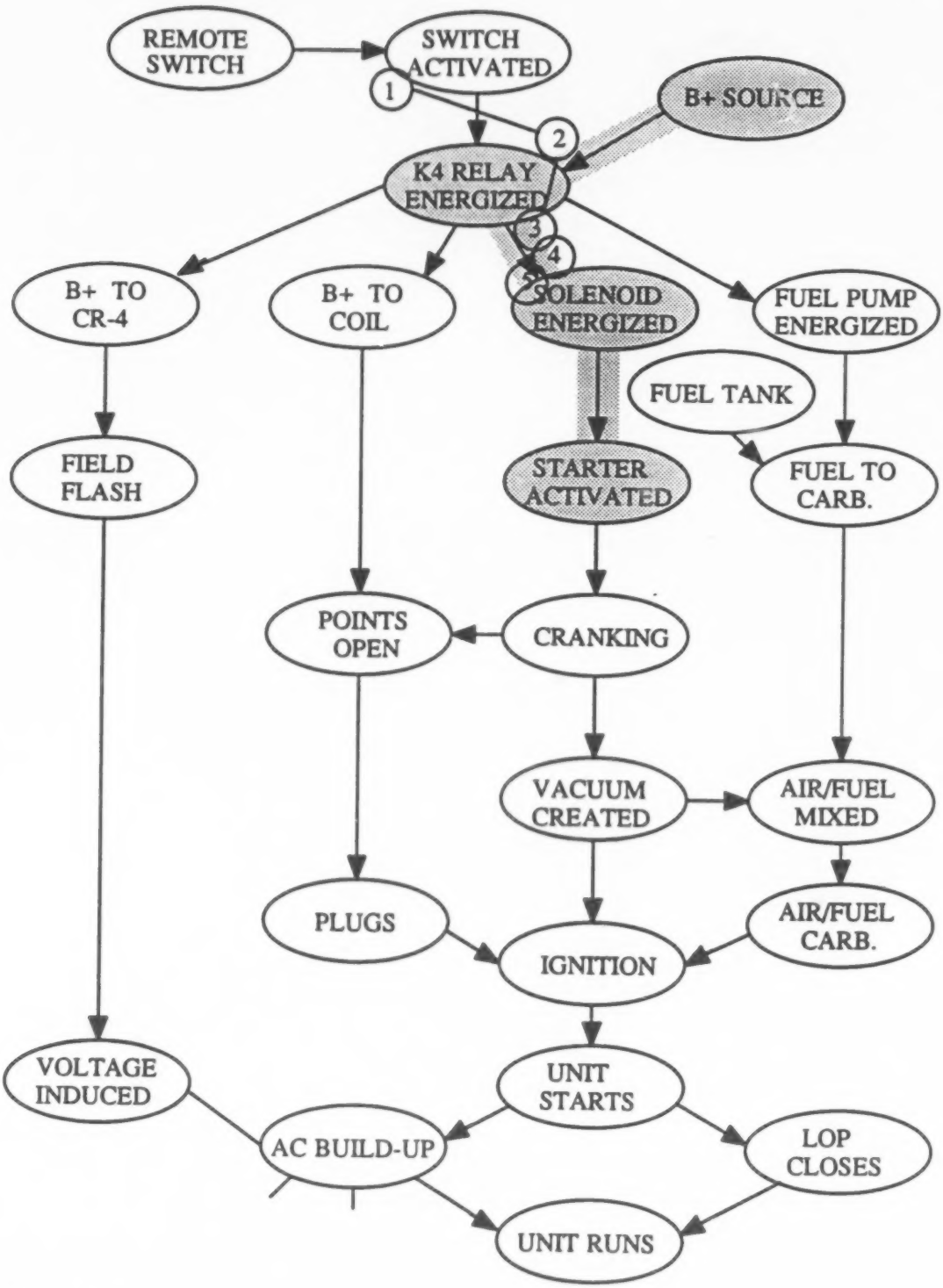


Figure 36. Experimental ss# 13 Problem Behavior Map

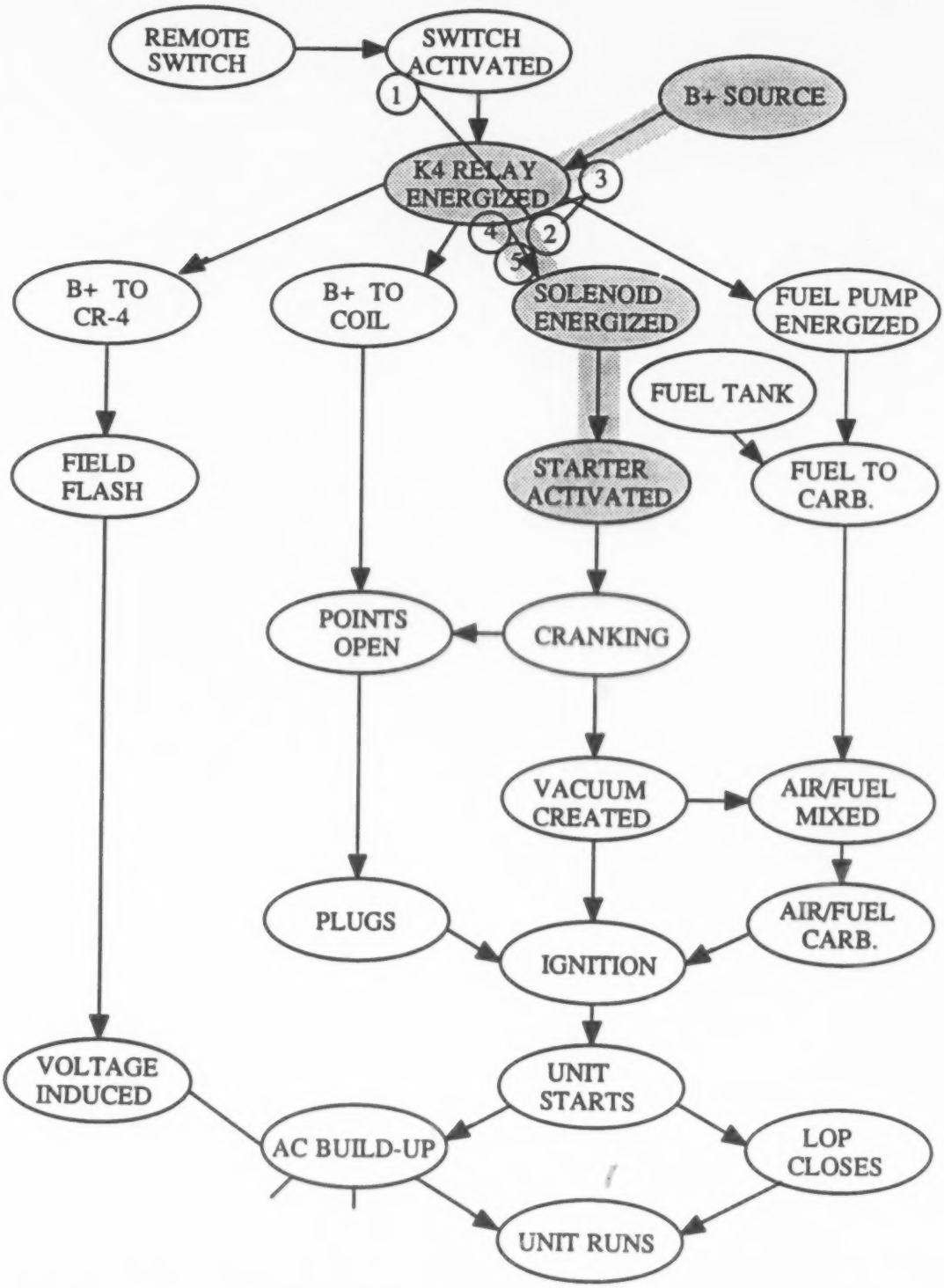


Figure 37. Experimental ss# 14 Problem Behavior Map

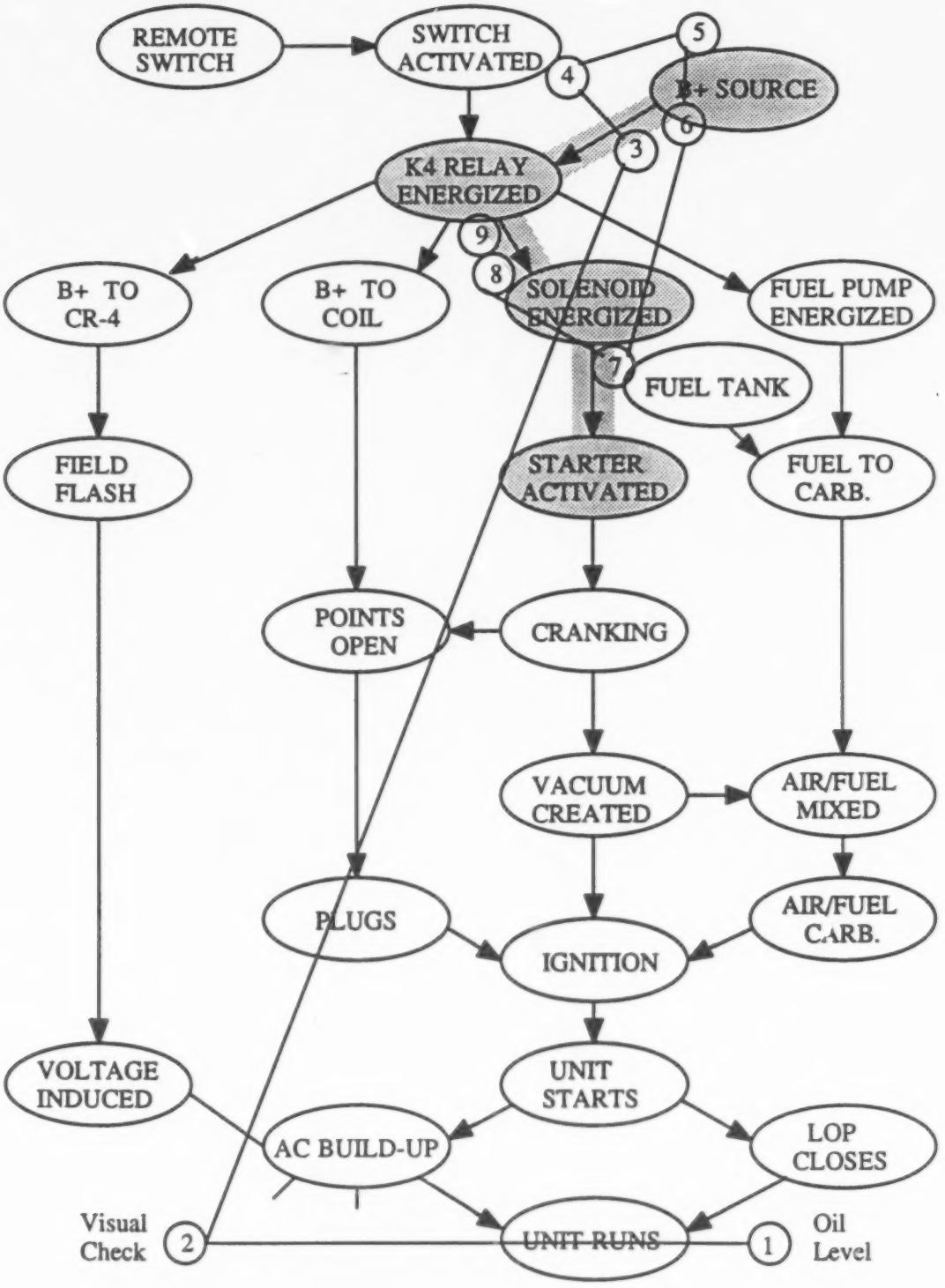


Figure 38. Experimental ss# 15 Problem Behavior Map

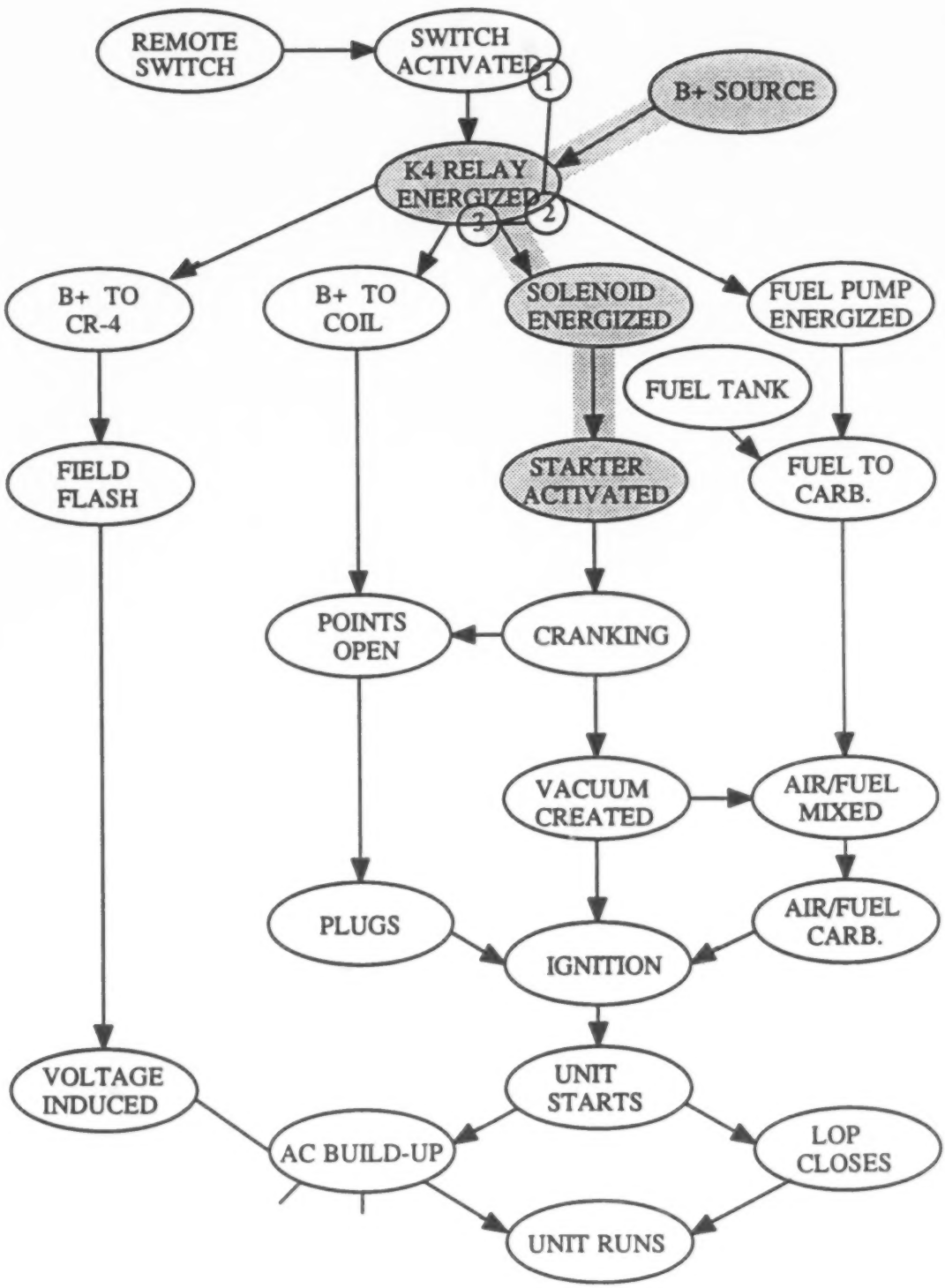


Figure 39. Experimental ss# 16 Problem Behavior Map